

EVALUATION OF ALTERNATIVES FOR
REMOVAL/DESTRUCTION OF PCB-CONTAMINATED
SEDIMENTS IN WAUKEGAN HARBOR

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EXECUTIVE SUMMARY

Sampling and analysis by both private and public organizations have confirmed the presence of polychlorinated biphenyls (PCB) in sediments of Waukegan Harbor and the North Ditch at levels as high as 30% on a dry weight basis. As a result, there is a need to determine the most cost effective means for removal/destruction of these environmental residues. Of necessity, such an evaluation must rely on data generated under different but related conditions since no restoration projects of this magnitude have ever been conducted in the U.S.

Waukegan Harbor is formed by an arm of Lake Michigan extending westward and north into the Illinois shoreline. PCB contamination in the predominantly sandy and silty sediments has been measured to a depth of 1.5 m (5 ft). It is estimated that of the total sediment load: 27,000 m³ (35,000 yd³) are contaminated at PCB — 100 mg/kg, 78,000 m³ (102,000 yd³) are contaminated at PCB — 10 mg/kg, and 132,000 m³ (178,000 yd³) are contaminated at PCB — 1 mg/kg.

The North Ditch lies to the north of Waukegan Harbor and serves as an industrial wasteway as well as a storm drain for over 65 acres of ground in the surrounding area. Sediments in the Ditch have been found to carry high concentrations of PCB to a depth of 2.1 m (7 ft) with an estimated 2900 m³ (3800 yd³) having PCB — 100 mg/kg. It is further calculated that 4800 m³ (6300 yd³) of sediments have PCB — 10 mg/kg and 7400 m³ (9300 yd³) have PCB — 1 mg/kg.

Of the technology available to remove, destroy, or immobilize PCB in sediments, only a small number of alternatives are sufficiently developed for large-scale application at this time. Historical data are limited to work in Japan, studies on the Hudson and James Rivers, and removal of some 250 gal of transformer fluid from the Duwamish River. Based on review of these incidents and an assessment of related technology, it has been determined that restoration of Waukegan Harbor could potentially be accomplished through one of three options:

1. In-place fixation
2. Removal of fixation
3. Removal and secured landfill.

In-place fixation is performed through application of technology developed in Japan for use on contaminated sediments in harbors. Specially formulated slurries of Portland cement are injected into the sediment deposits and allowed to solidify. Selection of dose level allows variation in product quality from an essentially concretized state to a form somewhat similar to aggregate soils.

Removal and fixation employs the same materials as in-place fixation, but relies on chemical addition after removal and solidification in an offsite area. Removal can be accomplished through use of any conventional dredging or excavation techniques. In Waukegan Harbor, viable alternatives are limited to: 1) a hydraulic suction pipeline dredge; 2) a pneumatic dredge of Italian design - the Pneuma; or 3) a vacuum-assisted pneumatic dredge of Japanese design - the Oozer. The shallow depth of the North Ditch and its physical boundaries limit removal options to the portable Mud Cat dredge (available from National Car Rental System, Inc.) or conventional excavation assisted by well point control of inflows.

Removal and disposal is accomplished in a manner similar to removal and fixation, except that secured landfill is employed for residuals management instead of fixation. Three sites were identified as candidate repositories for contaminated sediments. All were judged to have favorable geology for safe disposal of the spoils. None, however, is currently approved for receipt of PCB wastes. The Earthline landfill at Wilsonville, Illinois, has taken PCB wastes in the past but was recently closed by local litigation (the decision is under appeal). The Wayne County disposal site near Dearborn, Michigan, has also accepted PCB wastes in the past but has withdrawn its PCB disposal permit application in the past few months. The Browning-Ferris site at Zion, Illinois, is the closest of the three but has not applied for a PCB disposal permit. The nearest approved site is in Livingston, Alabama. Use of landfill disposal would also necessitate dewatering sediments and subsequent treatment of supernatant. This can be accomplished with polymer-assisted sedimentation and carbon adsorption if higher levels of removal are required.

During detailed evaluation of the three alternative approaches to restoration of Waukegan Harbor, it was determined that available options defined 35 different combinations which could be employed. The least costly of options for each approach addressing [PCB] ≥ 10 mg/kg were:

In-Place Fixation	\$1,430,000
Hydraulic Dredge with Onsite Fixation	1,962,000
Hydraulic Dredge with Secured Landfill	3,776,000

Uncertainty over long-term integrity of fixed sediments and the legal status of technology not allowed by PCB disposal regulations pursuant to the Toxic Substances Control Act render the two lower cost alternatives too questionable for large-scale use at this time. If in-place fixation is implemented to the point of concretization, all opportunity for modification of channel configuration to meet future needs is lost. Use of the less stable forms has not been studied with respect to leaching of PCB. Since

these workable forms involve lower doses of fixation, accelerated losses may be anticipated. Offsite fixation would be more acceptable since an impermeable seal could be employed to minimize water contact. This alternative, however, is presently outside of regulations and would therefore require a special exemption or modification of current regulatory language.

As a result of the above considerations, it is recommended that a hydraulic suction pipeline dredge be employed to remove contaminated sediments for Waukegan Harbor and discharge them in a sedimentation lagoon to be constructed nearby. After sediments have been dried to a 20 to 25% solids content, they should be hauled to Zion, Illinois, for burial. Total costs for the overall restoration of the Harbor will depend on the concentration of PCB to be removed:

[PCBs] \geq 100 mg/kg	= \$1,420,000
[PCBs] \geq 10 mg/kg	= 3,920,000
[PCBs] \geq 1 mg/kg	= 6,620,000

In the North Ditch, options provide 20 discrete combinations for restoration. Most cost-effective options for [PCB] \geq 10 mg/kg were estimated to be:

In-Place Fixation	\$182,000
Removal and Onsite Fixation	240,000
Removal and Secured Landfill	273,000

Removal is least costly when accomplished with a Mud Cat dredge. Once again uncertainty over long-term integrity and legality of fixation militates against its use at this time. Recommended action involves piping dredged sediment to a nearby settling lagoon and transport of dewatered solids to the Zion, Illinois, landfill. Spoils would be comingled with those from the Harbor and handled jointly. Total costs for the overall restoration of the Ditch vary with the concentration of PCB to be removed:

[PCB] \geq 100 mg/kg	= \$234,000
[PCB] \geq 10 mg/kg	= 312,000
[PCB] \geq 1 mg/kg	= 417,000

Implementation of the recommended course of action for both the Harbor and the Ditch will obligate expenditure of \$1,650,000, \$4,230,000, or \$7,040,000, depending upon the concentration of PCB to be removed.

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SECTION 1

INTRODUCTION

Sampling analysis by at least three organizations: Environmental Control Technology Corporation (ENCOTEC), Illinois Environmental Protection Agency, and the U.S. Environmental Protection Agency, has confirmed polychlorinated biphenyls (PCB) contamination in sediments of Waukegan Harbor and the North Ditch. These residuals are believed to have originated from discharges and losses of hydraulic fluids by a neighboring industrial facility. Subsequent investigations have indicated that residuals in the North Ditch are in the thousands of mg/kg (ppm) range and exceed 30% of the total solids in some places. Concentrations in Slips 1 and 3 and parts of the Harbor are lower, but often far exceed the 10 mg/kg (ppm) level utilized by the U.S. Environmental Protection Agency Region V as a threshold of definition for heavily polluted Great Lakes harbor sediments. As a consequence, there is a need to determine the most cost effective means of reducing PCB concentration in the Waukegan Harbor area.

The effectiveness of proposed approaches to eliminate contaminated sediments is dictated in large part by the physical-chemical properties of the toxic material. PCB is the common name employed to designate a family of compounds formed by chlorination of the biphenyl molecule. More than 150 distinct isomers of PCB can be formed and typical industrial products consist of a mixture of these isomers. Since it is often impossible to distinguish between specific isomers and mixtures in complex solutions, these materials are typically dealt with as total PCB.

PCB is an oily, viscous liquid soluble in water to 0.3 to 5 mg/l (ppm) depending on the degree of chlorination (the greater the chlorination, the lower the solubility). Like many chlorinated organic materials, it is highly soluble in organic solvents and partitions itself into these when contacted in two phase (water:organic) systems. This action stimulates concentration in fatty tissues and hence bioconcentration in the food chain. Similarly, it results in the sorption of PCB onto organic detritus and organic coatings on inorganic substrates in aquatic systems. PCB may also be bound to active inorganic surfaces such as those on clay particles. Hence, environmental residues are largely found associated with soils and sediments. By comparison, PCB concentrations in water are orders of magnitude below those on associated solids. PCB is relatively involatile, but has been found to enter the atmosphere through codistillation with surface waters. PCB is persistent in the environment as a result of its strong resistance to natural mechanisms of chemical, photochemical and biochemical degradation.

The work reported in this text was performed to provide technical and economic data required to select the preferred means for restoring the PCB-contaminated areas of Waukegan Harbor and the North Ditch. It must be recognized that massive clean-up efforts of this type have not been attempted in the U.S. to date. Therefore, such an undertaking must rely on data generated under different conditions or with other purposes intended. As a consequence, technical judgment plays a key role in the evaluation process. The approach taken here was designed to develop the ultimate recommendation as a result of a series of sequential evaluations, first selecting candidate approaches and then scrutinizing each approach in light of the specific needs in the Waukegan area.

This report contains a description of the site and a discussion of analytical data currently available, as well as a preliminary assessment of alternative approaches of restoration. Some overlap of the information will occur in order to provide the necessary details for each section. Candidate processes are identified as those approaches which are technically feasible and have been reduced to practice on a large scale. An in-depth evaluation is also presented on the use of each candidate approach, first in Waukegan Harbor and then in the North Ditch. This is followed by a comparative analysis of costs and other factors which must be considered in the selection process. Finally, specific restoration plan recommendations are given and implementation procedures detailed for the Harbor and the Ditch. Data for this work was obtained from site surveys, review of the literature, direct observations, discussions with pertinent industrial representatives, and engineering analysis.

SECTION 2

SUMMARY OF RECOMMENDATIONS

As a result of a preliminary assessment and subsequent detailed analysis, a number of alternatives have been evaluated for restoration of Waukegan Harbor and the North Ditch. Based on the evaluation, specific recommendations have been developed for implementation should restoration be initiated. The essence of these recommendations is given here. Considerations for implementation of recommendations are detailed in Section 6 of this report.

WAUKEGAN HARBOR

It is recommended that restoration of Waukegan Harbor be accomplished through removal and disposal of PCB-contaminated sediments. This should be accomplished in three sequential steps:

1. removal with a hydraulic pipeline dredge employing an intake cowl but no cutterhead
2. dewatering of sediments through polymer-assisted settling in a sedimentation lagoon
3. burial in the Browning-Ferris Landfill near Zion, Illinois.

All activities should be accompanied by a comprehensive schedule of sampling and analysis to monitor effectiveness.

The volume of sediments to be removed and, consequently, costs will depend upon the threshold level of PCB contamination selected for dredging. Costs for three candidate threshold levels are estimated at:

100 mg/kg (ppm) PCB	- \$1,420,000
10 mg/kg (ppm) PCB	- \$3,920,000
1 mg/kg (ppm) PCB	- \$6,620,000

The portion of the Harbor known as the Larsen Marine Boat Slip is best dredged using the Mud Cat dredge primarily selected for use in the North Ditch. This dredge is available from National Car Rental Service, Inc. on a term basis. Ample time will remain from the 2-month minimum rental period to accomplish dredging in the boat slip at no extra cost. Furthermore, the added maneuverability will provide more complete removal in the confines of the slip.

THE NORTH DITCH

It is recommended that restoration of the North Ditch be accomplished through removal and disposal of PCB-contaminated sediments. This should be accomplished in three sequential steps:

1. removal with the Mud Cat dredge
2. comingling with Harbor sediments for polymer-assisted dewatering in a sedimentation lagoon
3. codisposal with Harbor sediments in the Browning-Ferris landfill near Zion, Illinois.

Traffic should be rerouted in the Outboard Marine Corporation (OMC) parking lot, which forms the southern boundary of the Ditch, to allow sloughing of the south bank to a 1:1 slope or less. Upon completion of cuts, the bank should be restored with backfill and packed and paved for replacement of the road.

All activities should be accompanied by sampling and analysis. Again, the volume of sediments removed and, consequently, cost will vary directly with the threshold level of PCB contamination selected for removal. Costs for three candidate thresholds are estimated at:

100 mg/kg (ppm) PCB -	\$234,000
10 mg/kg (ppm) PCB -	\$312,000
1 mg/kg (ppm) PCB -	\$417,000

If restoration cannot be accomplished prior to spring runoff, interim measures may be necessary to prevent flushing of contaminated sediments to Lake Michigan. It is recommended that this be accomplished using a gravity flow culvert in the ditch bed or pumped transfer of flow to the North Shore Sanitary District Wastewater Treatment facility depending upon the delays anticipated in initiating restoration. If the delay is likely to exceed 1.5 years, the gravity system is recommended at an estimated cost of \$57,000. The pumped system would have an estimated capital cost of \$19,760 and annual operating costs of \$21,300.

SECTION 3

SITE DESCRIPTION

Waukegan, Illinois, lies on the western edge of Lake Michigan, nearly 48 km (30 mi) north of Chicago and just south of the Illinois-Wisconsin border (Figure 1). The city itself encircles the irregular-shaped harbor and is drained in part by a small drainage ditch entering the Lake just north of the Harbor. The sediments of these two water bodies, the Harbor and the North Ditch, have been found to be heavily contaminated with PCB. The physical characteristics and patterns of contamination differ significantly between the Ditch and Harbor and, consequently, are reviewed independently.

WAUKEGAN HARBOR

The Harbor is a branched member resembling the letter L as it runs north to south and then turns a right angle east to enter the Lake. Water depth averages 4.9 to 6.1 m (16 to 20 ft) but varies with location and time. The U.S. Army Corp of Engineers is responsible for the dredge maintenance of the main entrance channel. On the average, they dredge 23,000 m³ (30,000 yd³) per year from this area. No maintenance dredging has been performed since the contamination was discovered. Results of measurements by the Illinois Environmental Protection Agency are compared to charted values for water depth in Figure 2. Water quality is similar to that found in nearby portions of Lake Michigan with somewhat higher levels of certain dissolved salts and nitrogenous matter (Table 1). Test results, as shown in Table 1, appear to reflect low levels of industrial discharges sustained by the Harbor and a reduced level of mixing between the Harbor and Lake. In a recent preliminary engineering analysis, Environmental Control Technology Corporation (ENCOTEC) determined that major mixing mechanisms resulted from wind action and longshore currents. These may stimulate displacement of the entire volume of Harbor water each 2 to 4 weeks.

Sediments are composed predominantly of sand, and sand and gravel in shallower zones with silt, and sand and silt in deeper waters. These zones are underlain by a layer of hard clay (the natural harbor bottom) some 6.4 m (23 ft) below the surface of the water. Samples taken in the area of Slip 3 during the June 9, 1976, sampling by the U.S. EPA were observed to contain oils and have a petroleum odor but no benthos. Less oil was evident south of this region, where benthos were present.

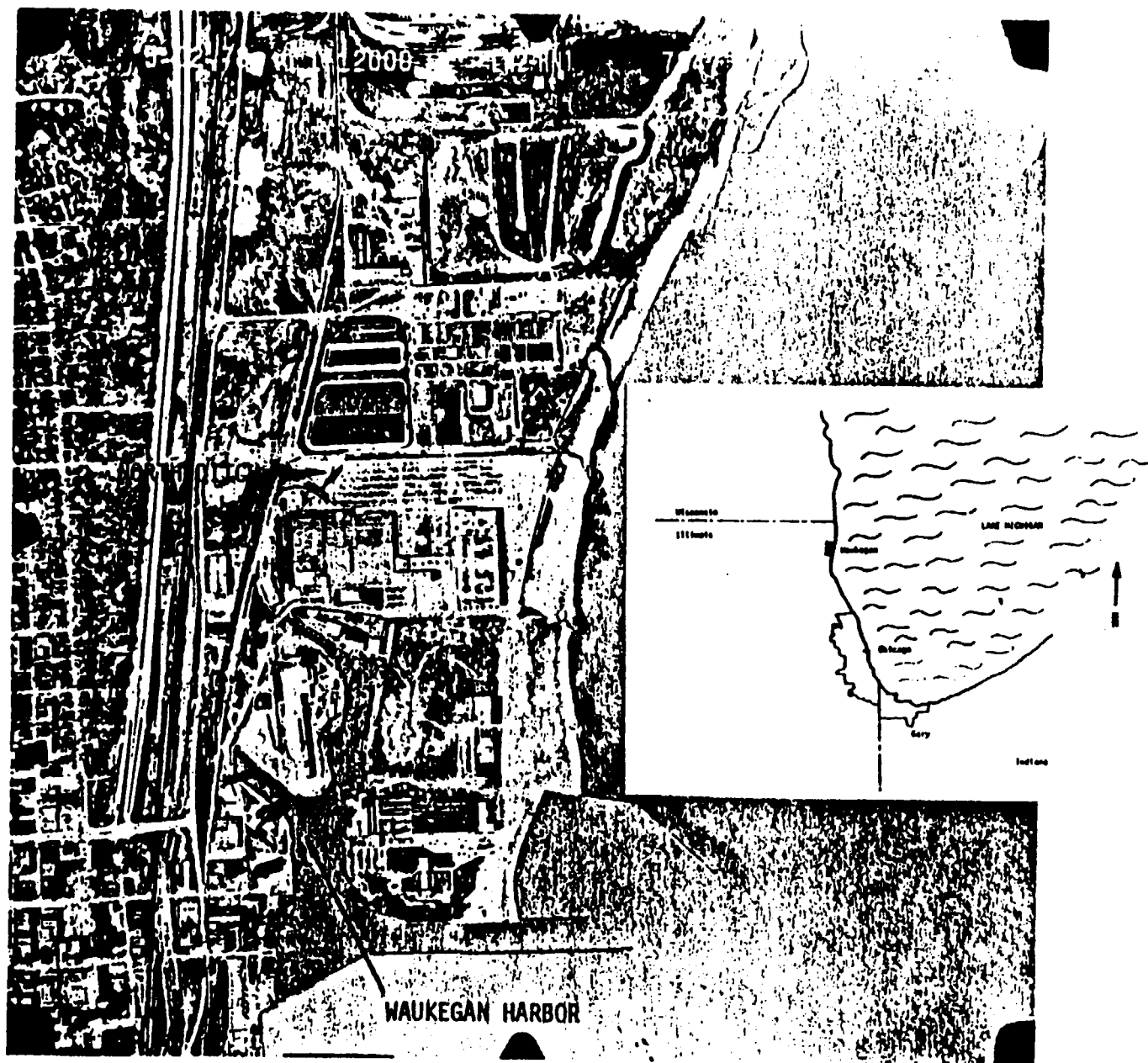


FIGURE 1. Aerial Photo of Harbor and Ditch

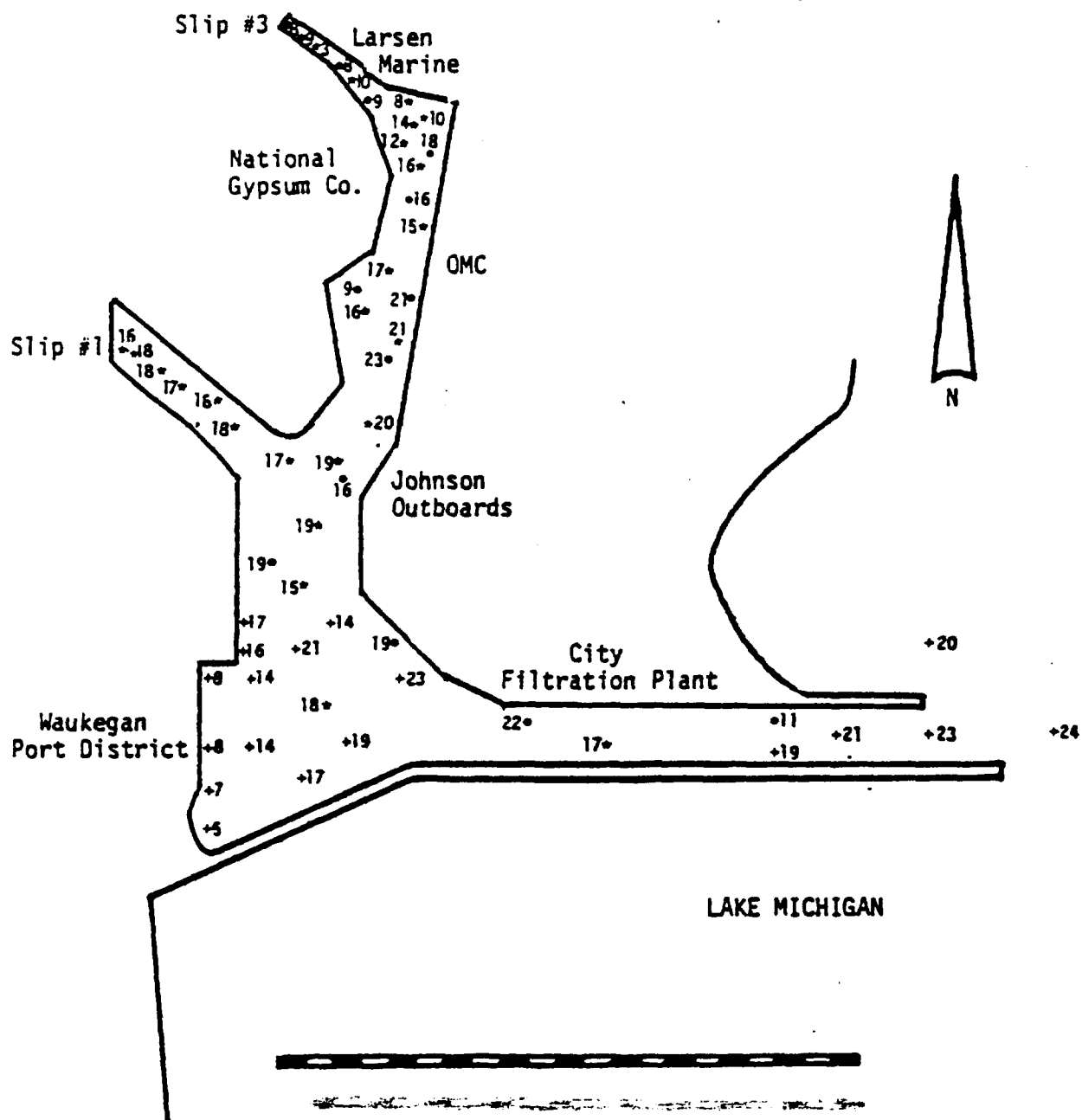


FIGURE 2. Water Depth as Determined on February 16-18, 1977 in Ft
 * values from Illinois Environmental Protection Agency
 (May, 1977)
 * Values from USGS Chart 14904, 18th Ed., September 6, 1975
 + Values from U.S. Army Corps of Engineers Soundings
 (May, 1977)

TABLE 1. Comparison of Water Quality Ranges - Waukegan Harbor and Lake Michigan North of the North Breakwater (ENCOTEC, 1977)

Parameter	Units	Range of Values (February/April 1977)	
		Lake Michigan	Waukegan Harbor
pH	SV	7.75-8.16/8.02-8.35	7.00-7.86/7.38-7.90
Alkalinity	mg/l as CaCO ₃	111-121/108-112	112-123/110-112
BOD	mg/l	2-4/1-3	3-5/2-3
Total Suspended Solids	mg/l	5-50/2-3	2-16/1-6
Total Dissolved Solids	mg/l	164-185/154-632	188-228/172-274
Specific Conductance	µmhos/cm @ 25 C	260-310/270-290	310-360/270-300
Chloride	mg/l	15-18/9-12	22-30/11-15
Sulfate	mg/l	25-34/20-25	27-30/23-29
Ammonia-Nitrogen	mg/l	0.08-0.47/0.05-0.36	0.42-0.98/0.24-0.64
Total Kjeldahl Nitrogen	mg/l	0.2-1.2/0.1-1.1	0.5-1.6/0.4-0.9
Nitrate, Nitrite Nitrogen	mg/l	0.30-0.35/0.18-0.23	0.30-0.37/0.23-0.26
Total Phosphorus	mg/l	0.014-0.081/0.02-0.53	0.019-0.081/0.02-0.03
COD	mg/l	7-15/<5-8	7-14/<5-11
Total Organic Carbon	mg/l	3-4/3-4	3-5/0.4
Soluble Organic Carbon	mg/l	2-3/1-3	3-4/2-4
Grease and Oil	mg/l	1/1-3	1-2/<1-3
Sodium	mg/l	6.3-8/4.6-6.6	8.8-14/5.6-7.7
Potassium	mg/l	1.4-1.6/1.1-1.4	1.5-1.6/1.2-1.4
Magnesium	mg/l	12-14/11-12	41-43/11-12
Calcium	mg/l	40-44/44-45	12-13/45-48
Hardness	mg/l as CaCO ₃	150-170/160	150-160/160-170
Aluminum	mg/l	0.10-0.58/0.16-0.61	0.12-0.24/0.12-0.28
Arsenic	mg/l	0.003-0.006/0.002-0.004	0.004-0.009/0.004-0.007
Cadmium	mg/l	≤0.0001/0.0001	0.001-0.003/0.0001-0.0002
Chromium	mg/l	0.017-0.043/0.006-0.036	0.015-0.006/0.004-0.038
Copper	mg/l	0.001-0.004/0.002-0.003	0.002-0.005/0.001-0.002
Iron	mg/l	0.08-0.69/0.002-0.003	0.16-0.28/0.07-0.27
Lead	mg/l	≤0.002/≤0.001	0.003-0.014/0.001-0.006
Manganese	mg/l	0.003-0.019/0.002-0.008	0.012-0.019/0.008-0.027
Mercury	mg/l	≤0.0001/≤0.0001	≤0.0001/≤0.0001
Nickel	mg/l	≤0.001/≤0.001-0.02	≤0.001/0.001-0.002
Zinc	mg/l	0.01-0.02/≤0.01	0.02-0.03/≤0.02
Total Chloride	mg/l	0.01-0.03/≤0.01	0.01-0.02/≤0.01
Total Phenol	mg/l	≤0.001-0.005/0.002-0.005	0.008-0.066/0.009-0.024

Three organizations have reported on analysis of sediments for PCB as presented in Figures 3 through 7. Based on these analyses, it appears that surface values are highest in Slip 3, where they exceed 10,000 mg/kg (ppm). Concentrations are lower south of the slips and in the east-west channel of the Harbor to the Lake. At the Harbor Light Horn, total PCB concentration is down to 1 mg/kg (ppm). PCB concentrations also decrease with depth as illustrated in Figures 8 through 10. The deepest penetration of PCB at 1 mg/l (ppm) or greater occurs at the southern portion of the Harbor just before the channel turns east.

Based on plots of the data presented in Figures 8 through 10 and use of a planimeter, it is estimated that up to 27,000 m³ (35,000 yd³) are contaminated with PCB at 100 mg/l (ppm) or greater. Up to 78,000 m³ (102,000 yd³) are contaminated at 10 mg/l (ppm) or greater, and 132,000 m³ (173,000 yd³) at 1 mg/l (ppm) PCB or greater. These estimates yield the relation between volume of sediments and contamination level plotted in Figure 11.

THE NORTH DITCH

The North Ditch (Figure 12) functions as a natural drainage channel and wasteway in the Waukegan area. As depicted in Figure 13, it flows west to east entering Lake Michigan just north of Waukegan Harbor. It has an average width of 6 m (20 ft) at the base and 9 m (30 ft) at the top, and a run of 824 m (2700 ft) from the railroad tracks to its mouth at Lake Michigan. The depth from the banks to the top of water surface averages 1.5 m (5 ft). Dry weather flow has been estimated by ENCOTEC at 1.4 l/sec (0.05 cfs). However, in extremely dry weather flow does not enter the lake but percolates through the ditch bottom to recharge ground water. Flow derives both from industrial outfalls and from surface water drainage covering roughly 260,000 m² (65 acres). As a consequence, it is estimated that during a 5-year storm event of 3 hr. duration, flow will reach 2100 l/sec (75 cfs). Occasionally during periods of storm, winds off of Lake Michigan form shoals of sand across the mouth. These block natural flow and raise the water level in the Ditch until erosion or human intervention clears the channel. There is an adverse gradient in the final 240 m (800 ft) of the Ditch.

The south bank of the Ditch consists of natural soils and gravel while the north bank has been bolstered by the North Shore Sanitary District with sheet piling. Surface sediments in the Ditch consist mainly of black grit, silt and detritus. While some benthic life was observed midway between the railroad tracks and the mouth, there were no benthos found upstream or downstream of that site. ~~Downstream sampling sites~~ are underlain by a layer of coarse gray material. Most sediments were found to have a definite petroleum odor and medium to heavy visible oil. Observations by ENCOTEC indicate no visible sediment transport during dry weather flow. Smaller particles (silts) may be transported during periods of runoff.

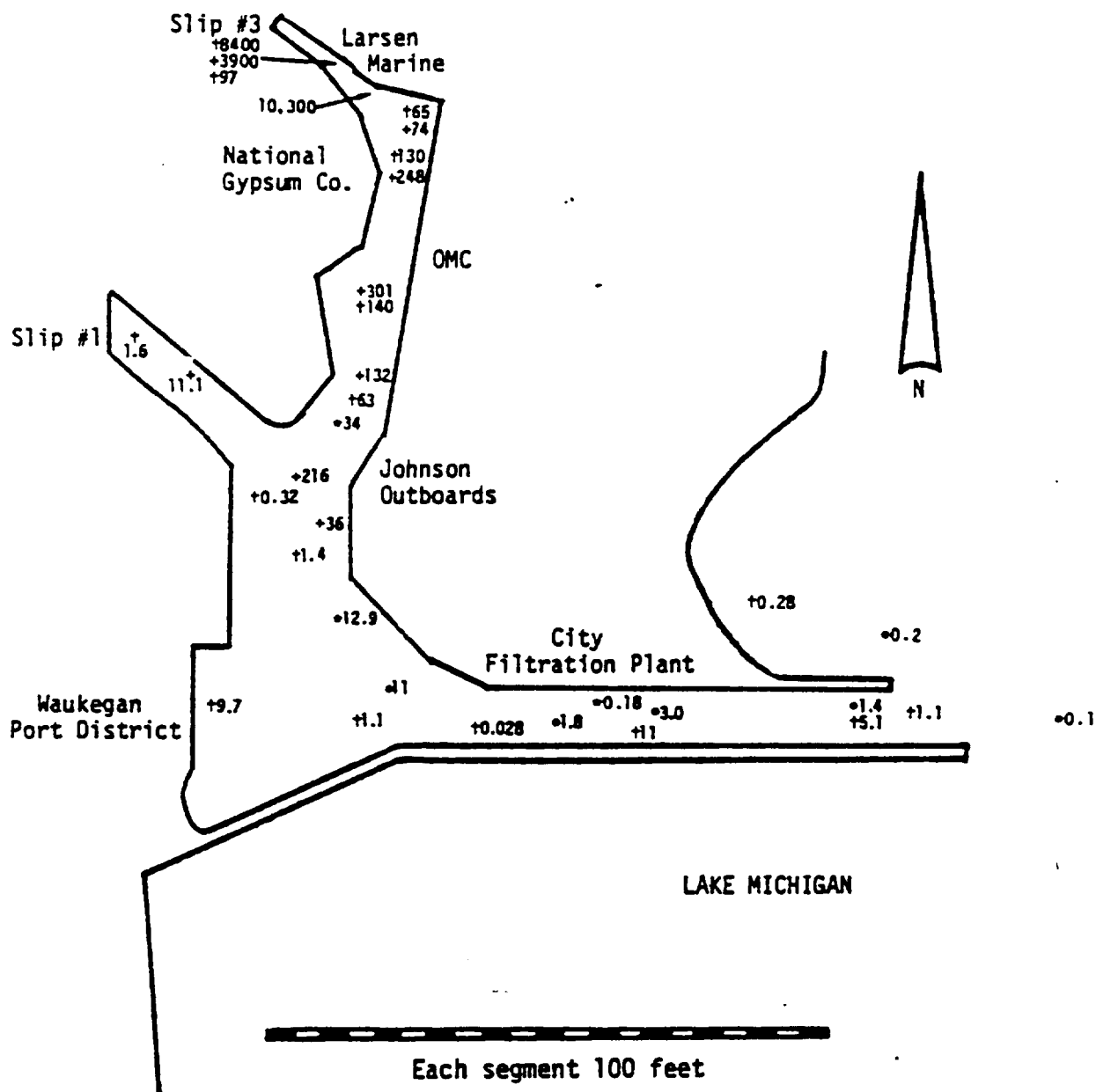


FIGURE 3. PCB Concentrations in the Top 1 Ft of Sediments (mg/kg-ppm)

- U.S. EPA Grab Samples, 5/12/76
- + U.S. EPA Grab Samples, 6/9/76
- * Illinois EPA Core Samples, 2/16-18/77
- + ENCOTEC Core Samples, April, 1977

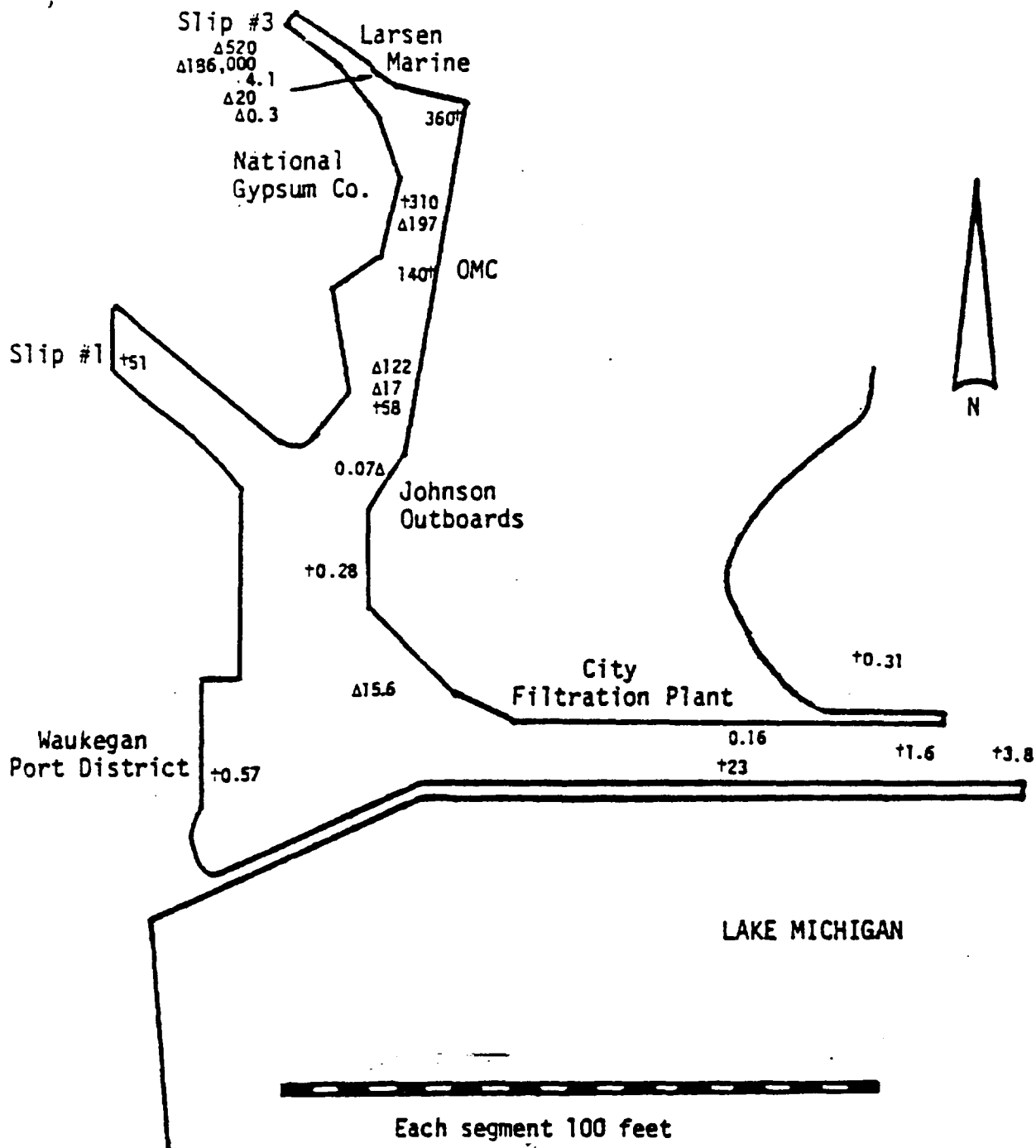


FIGURE 4. PCB Concentrations at 1 to 2 Ft Depth in Sediments (mg/kg-ppm)
 Δ Illinois EPA Core Samples, 2/16-18/77
 + ENCOTEC Core Samples, April, 1977

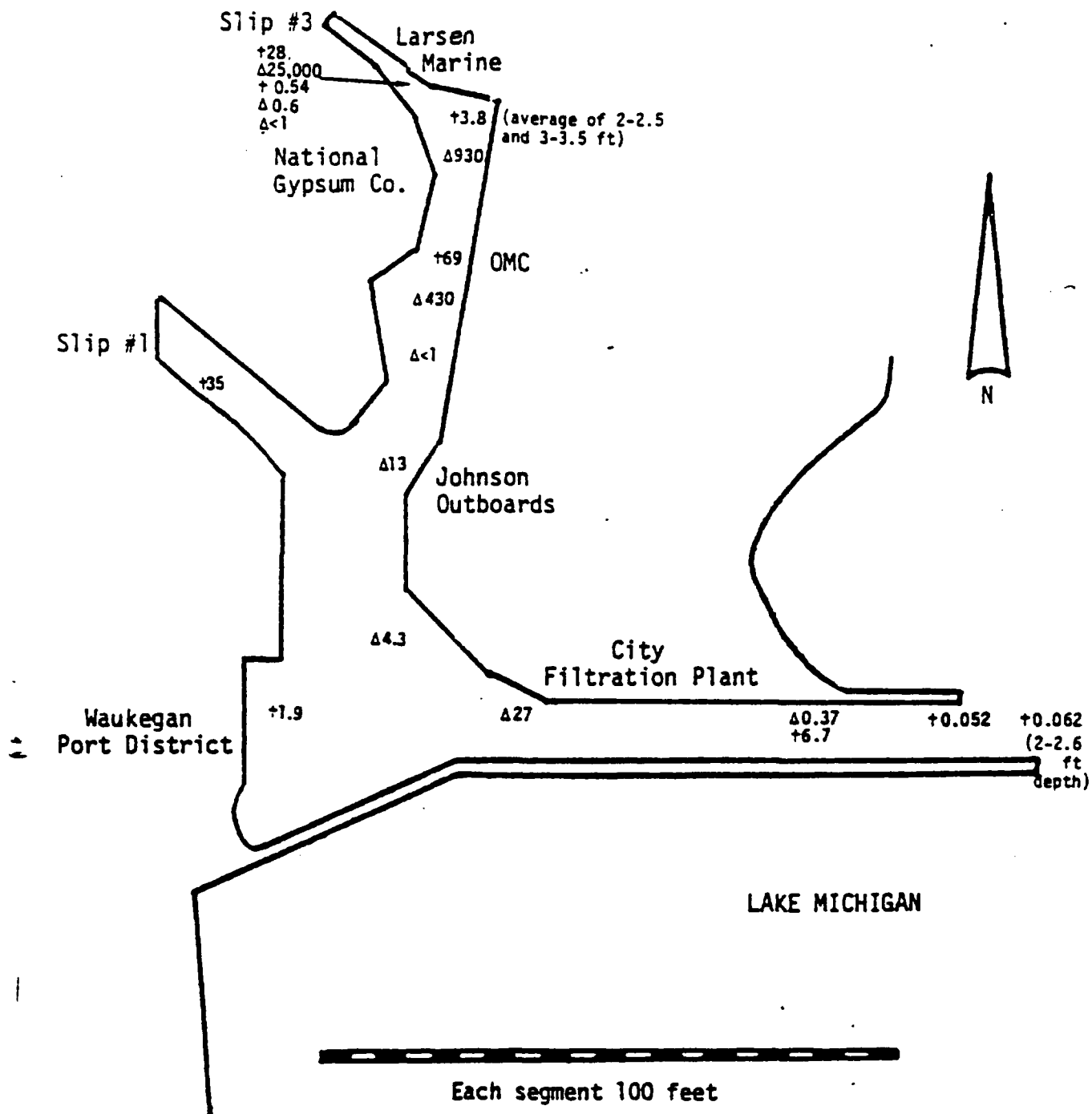


FIGURE 5. PCB Concentrations at 2 to 3 Ft Depth in Sediments (mg/kg-ppm)
 Δ Illinois EPA Core Samples, 2/16-18/77
 + ENCOTEC Core Samples, April, 1977

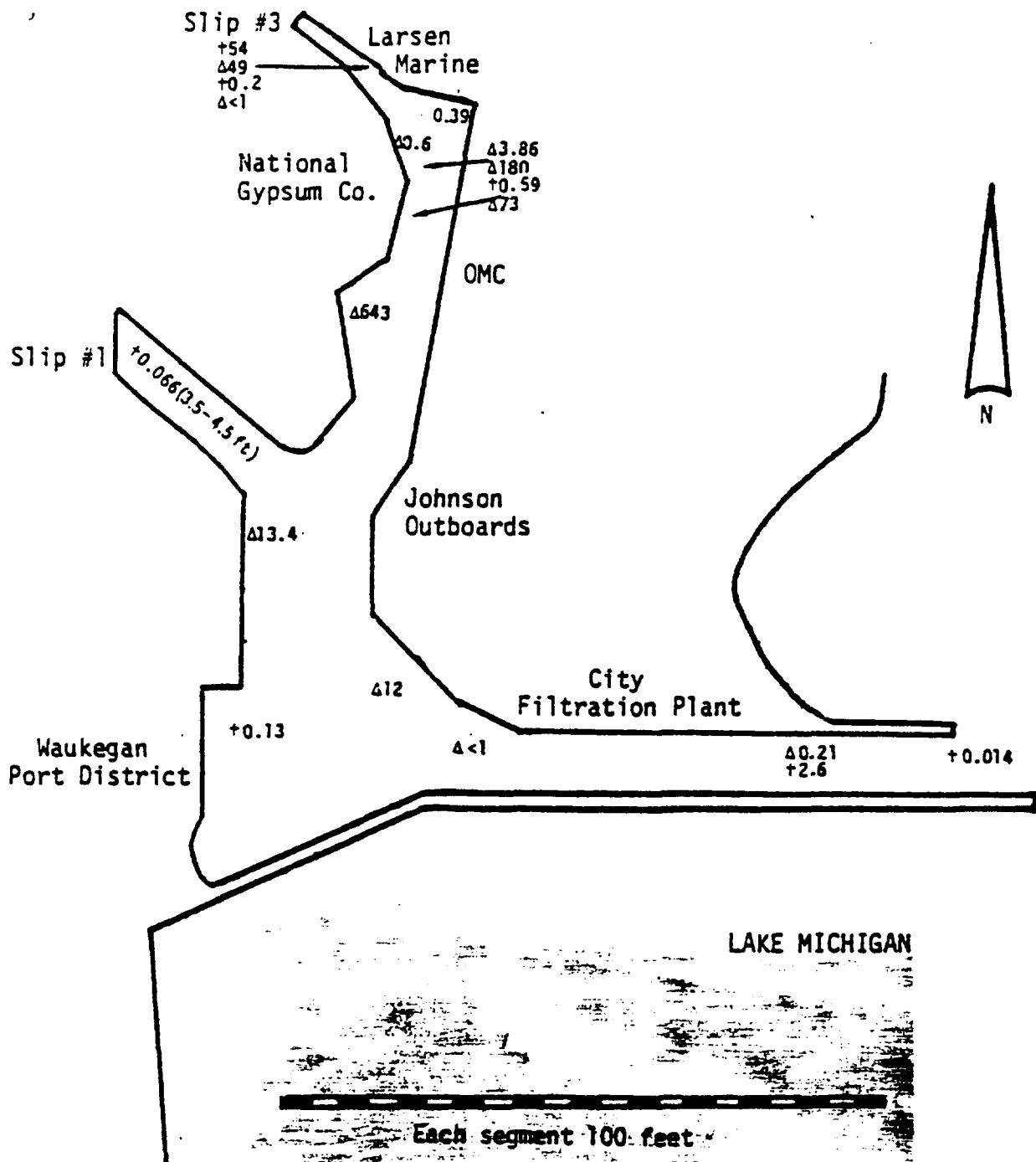


FIGURE 6. PCB Concentrations at 3 to 4 Ft. Depth in Sediments (mg/kg-ppm)
 Δ Illinois EPA Core Samples, 2/16-18/77
 + ENCOTEC Core Samples, April, 1977

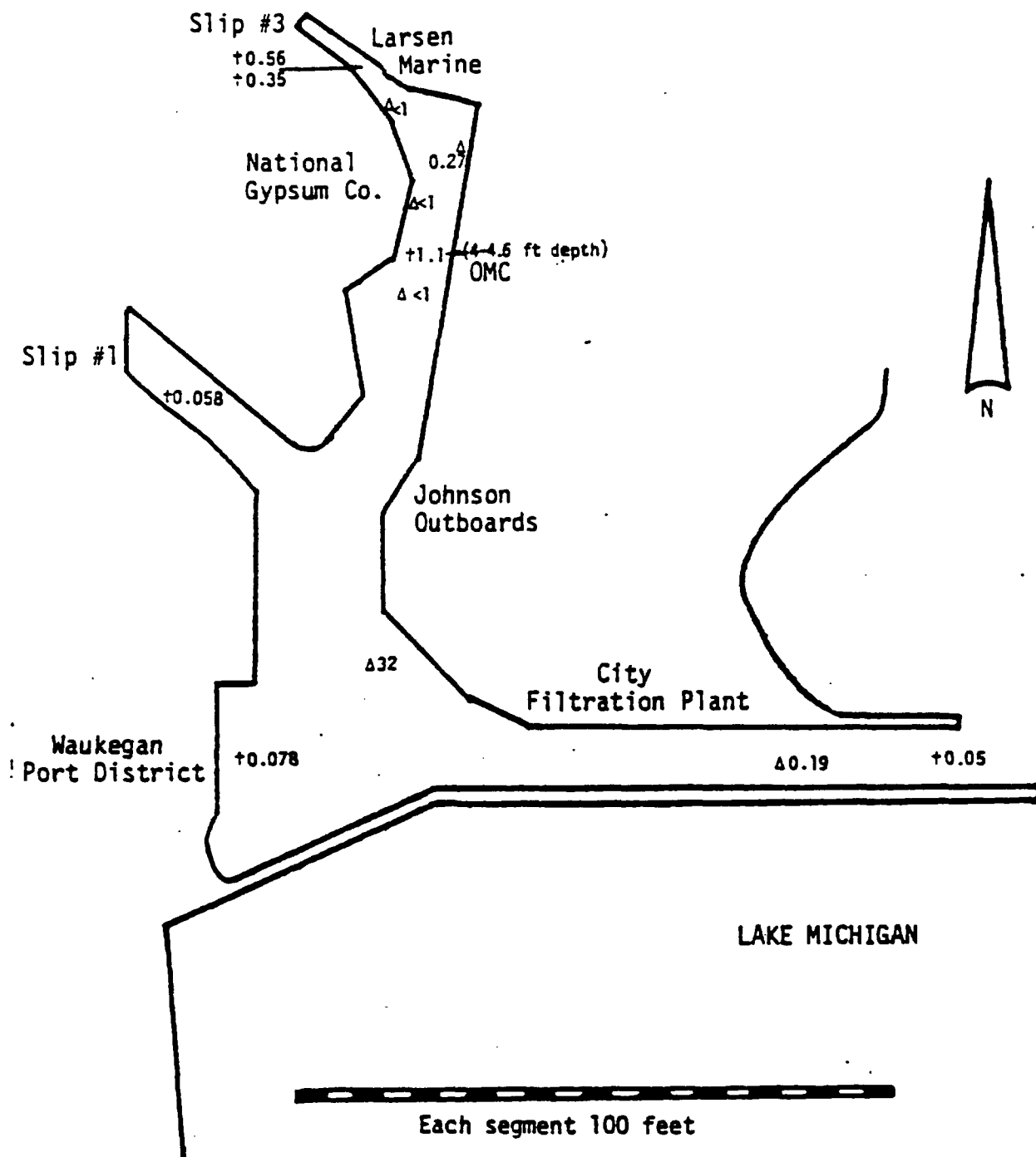


FIGURE 7. PCB Concentrations at 4 to 5 Ft Depth in Sediments (mg/kg-ppm)
 Δ Illinois EPA Core Samples, 2/16-18/77
 + ENCOTEC Core Samples, April, 1977

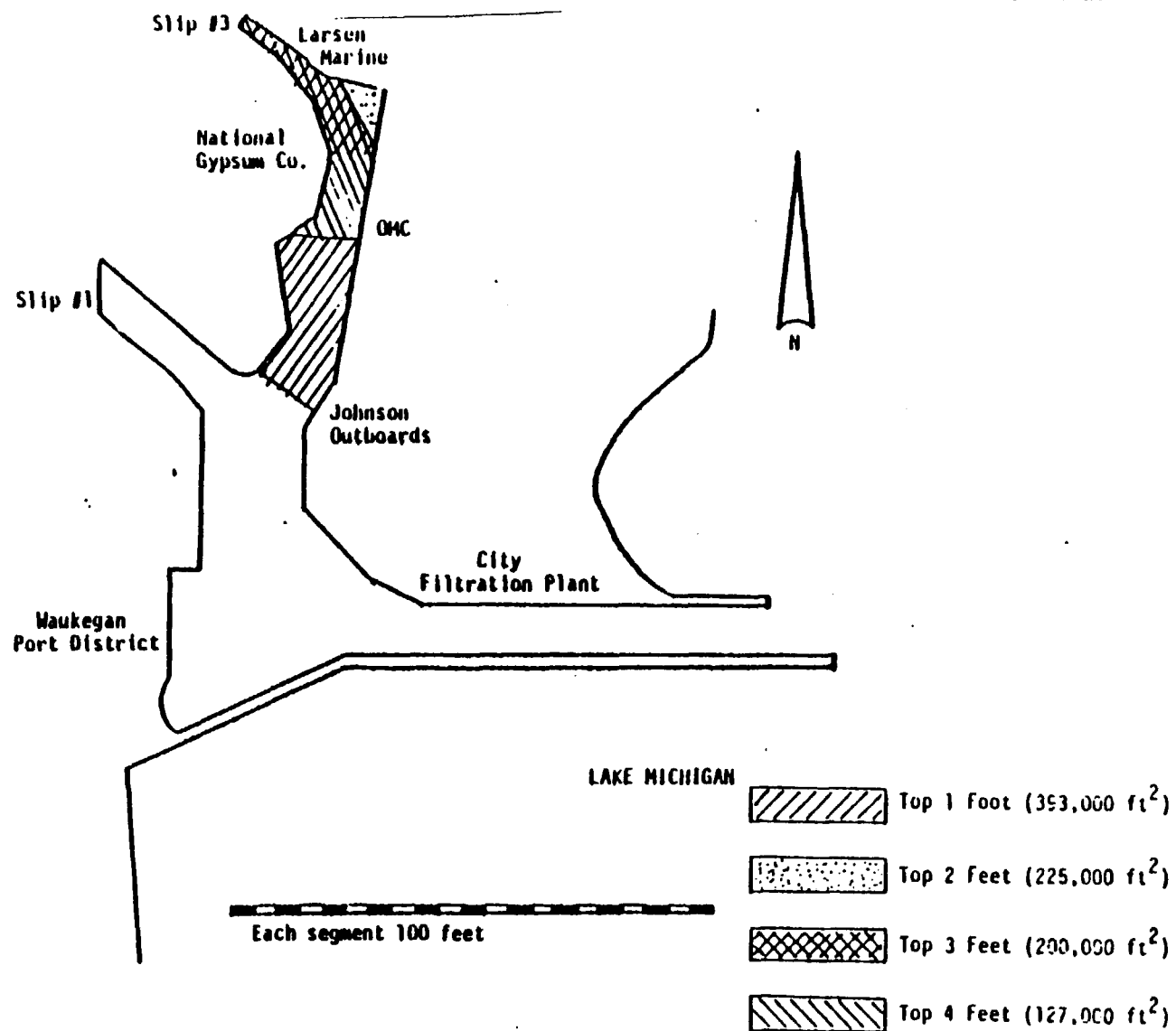


FIGURE 8. Zones with Contamination at PCB \geq 100 mg/kg-ppm

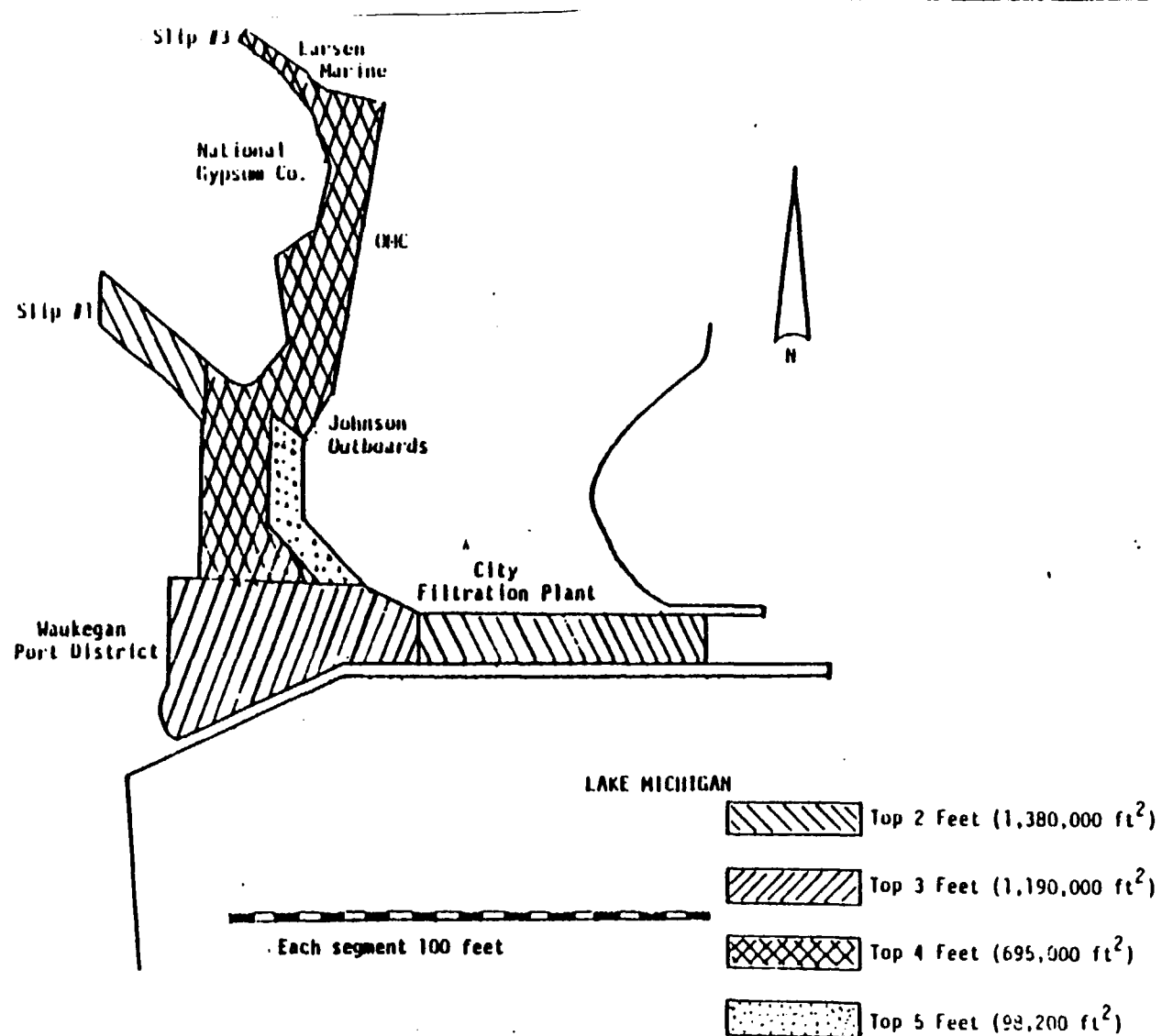


FIGURE 9. Zones with Contamination at PCB \geq 10 mg/kg-ppm

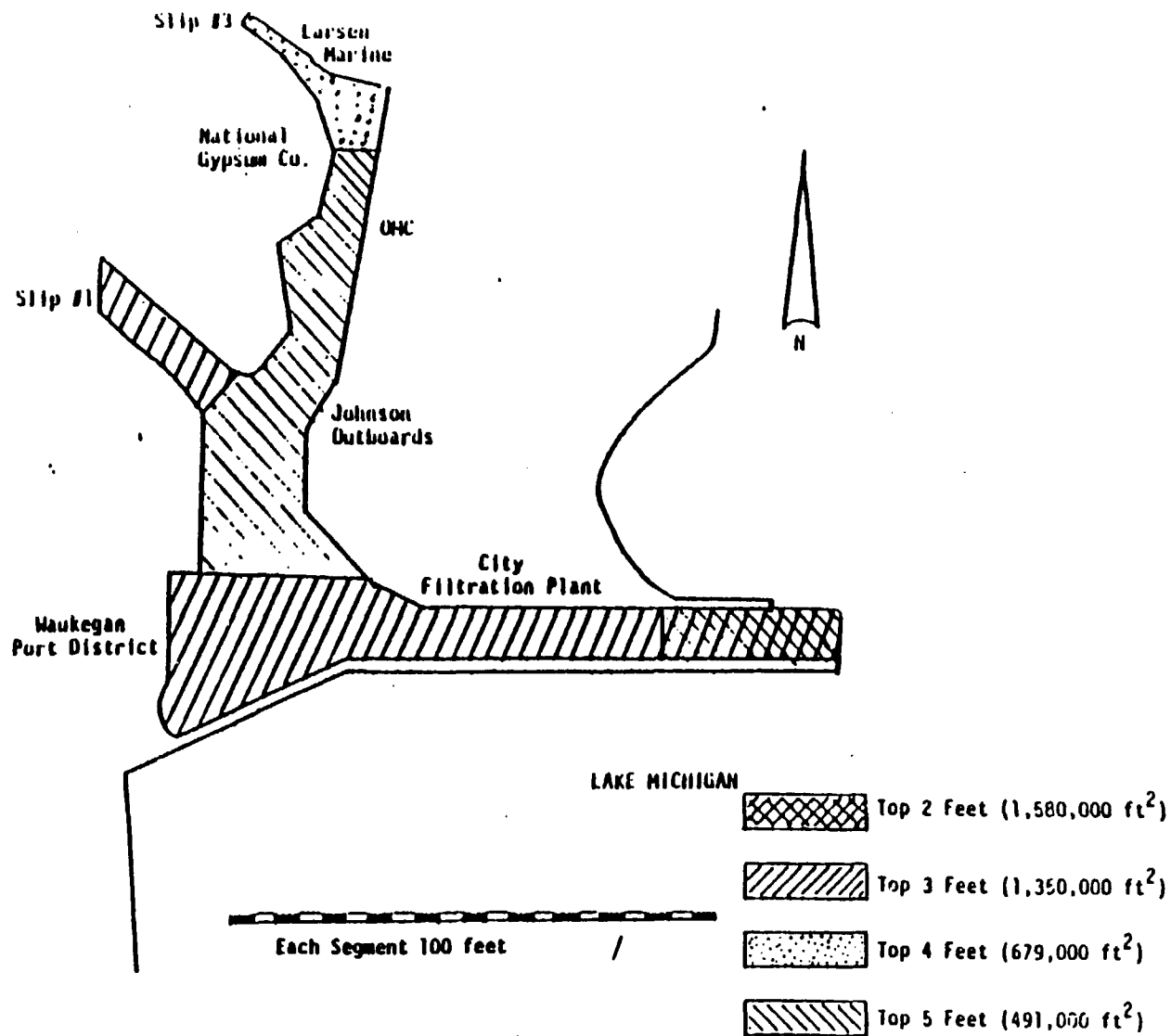


FIGURE 10. Zones with Contamination at PCB \geq 1 mg/kg-ppm

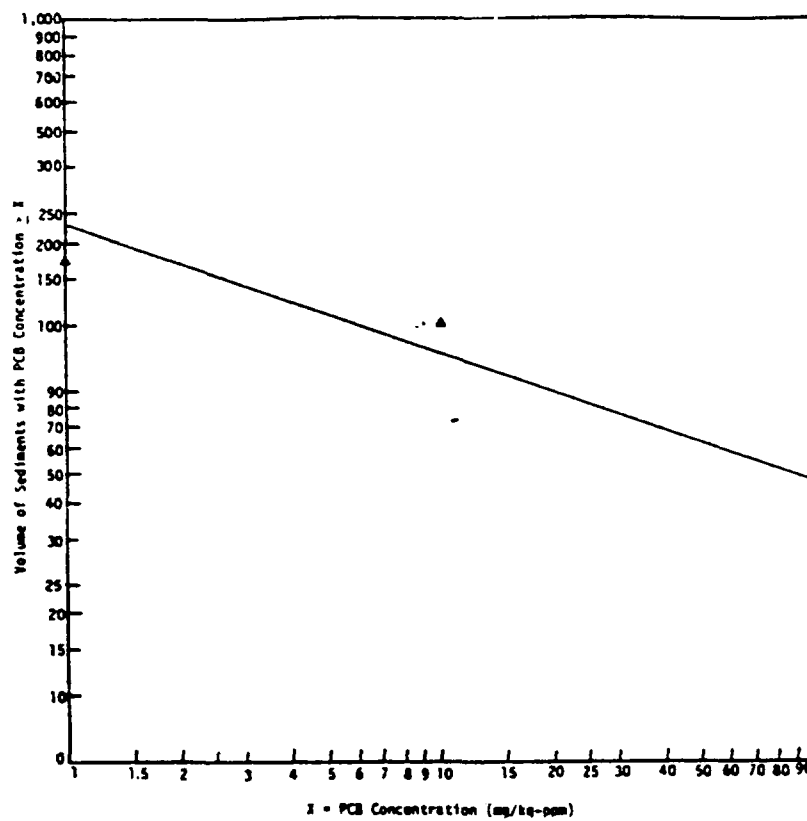


FIGURE 11. Volume of Sediments Contaminated to a Given PCB Concentration or Greater in Waukegan Harbor



FIGURE 12. View of the North Ditch Looking Eastward to the Mouth

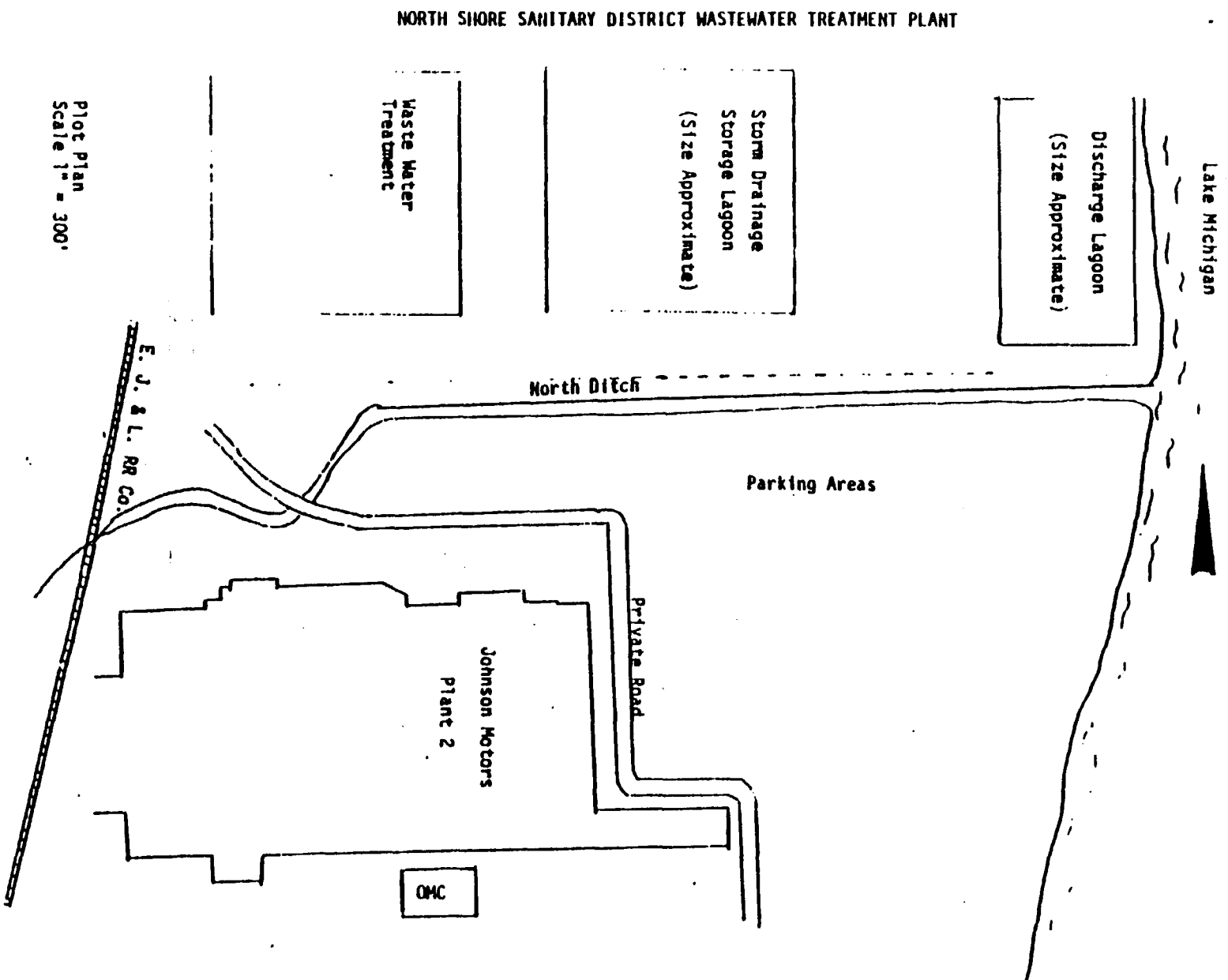


FIGURE 13. Location of North Ditch

PCB contamination is extremely high in all surface sediments and runs to a depth of from 1.5 to 2.1 m (5 to 7 ft) as presented in Figure 14. The highest concentration of PCB occurs at the reach just upstream of the private road crossing where a sample at 0.9 m (3 ft) exceeded 35% PCB on a dry weight basis. Limited duplication of samples reveals no major differences in PCB content between adjacent sites. Hence, samples are believed to be representative of values for a given transient. Calculations made through the use of data plots and a planimeter result in an estimate of 2900 m³ (3800 yd³) of sediments contaminated at 100 mg/kg (ppm) or greater, 4800 m³ (6300 yd³) at 10 mg/kg (ppm) or greater, and 7400 m³ (9700 yd³) at 1 mg/kg (ppm) or greater. The relation between volume of sediment and level of contamination is presented in Figure 15.

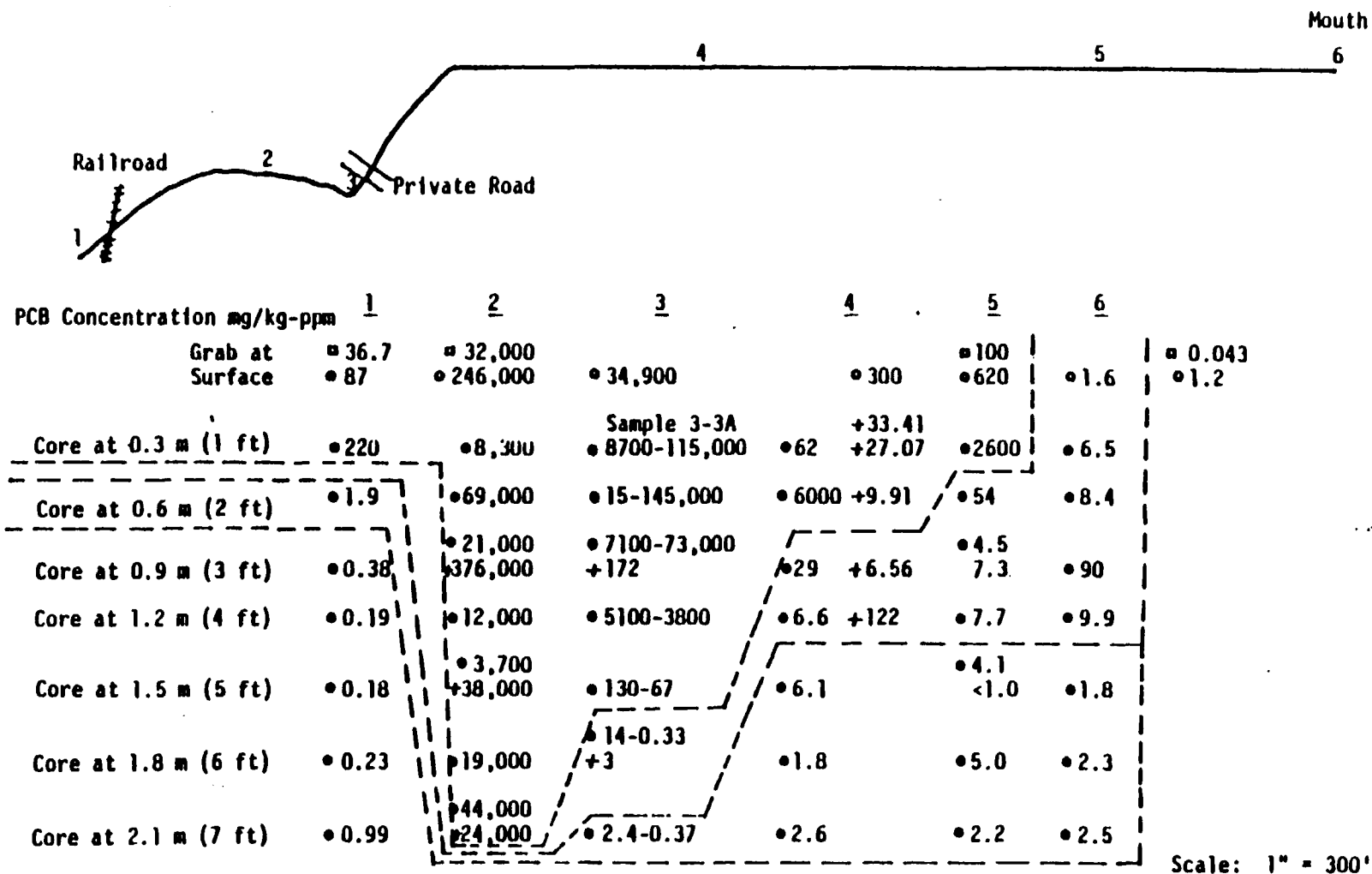


FIGURE 14. PCB Concentration Profile in the North Ditch

• USEPA June 9, 1976
 □ Illinois EPA June 9, 1976
 + Illinois EPA 2/16-18/1977
 • ENCOTEC April 1977

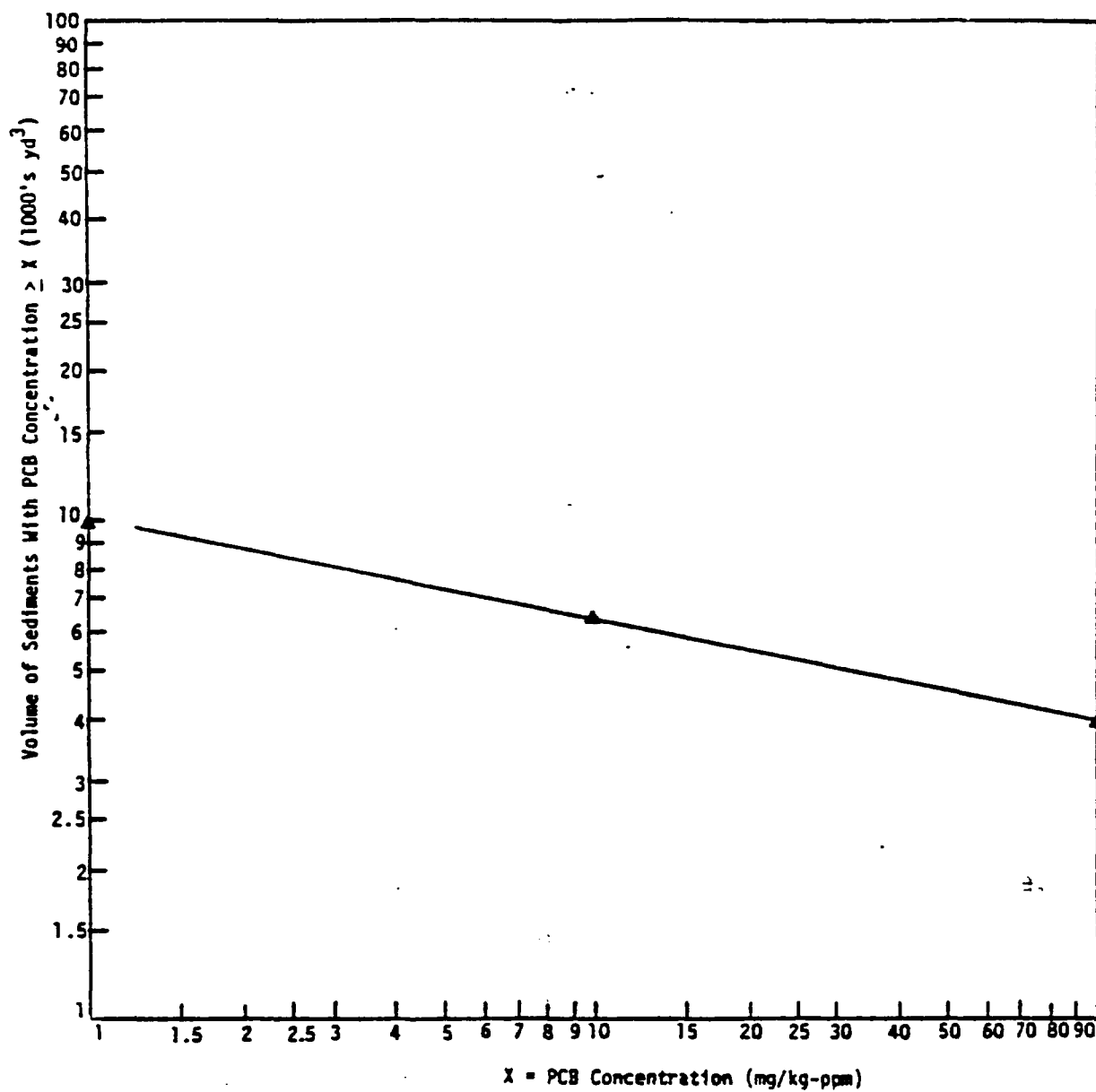


FIGURE 15. Volume of Sediments Contaminated to a Given PCB Concentration or Greater in North Ditch

SECTION 4

PRELIMINARY ASSESSMENT OF ALTERNATIVES

The discovery that soils and sediments, particularly those underlying navigable waters of some industrialized countries are contaminated with in-place toxic substances has been relatively recent. As a consequence, a limited array of technology has been developed and tested for reducing pollution. The most notable evaluations and application efforts have been conducted in Japan (PCB), the Hudson River (PCB), the Duwamish (River (PCB), and the James River (Kepone). In these efforts, it was determined that potential alternatives could be divided into three basic approaches: 1) in-place destruction, 2) in-place fixation or immobilization, and 3) removal with subsequent treatment and disposal. Individual alternatives within these broad categories have been brought to varying levels of development as discussed below.

IN-PLACE DESTRUCTION

In-place toxic substances other than elemental species offer the opportunity for destruction or reduction to less hazardous forms. The mechanisms and reagents which can be employed to accomplish this differ with the chemistry of the contaminant. Previously referenced work in the Hudson and James Rivers has identified several options which can be applied to chlorinated organics. These include: ultraviolet radiation/ozonolysis (UV/ozonolysis), biodegradation, chemical oxidation, gamma radiation (Y-radiation), and electron beam radiation. Use of these alternatives is not restricted to in-place application. These technologies can also be used to destroy PCB on dredged materials prior to disposal.

The UV/ozonolysis process has been most recently demonstrated by Westgate Research, Inc. in San Diego, California. Development has been based on the discovery that while direct ultra-violet radiation and ozone applied independently were relatively ineffective in degrading chlorinated hydrocarbons, their joint action would lead to significant oxidation. Tests with solutions of PCB and Kepone produced substantial reduction in the parent compound with exposure times of 1 hr or less. No attempt was made to characterize end-products or their toxicity. The technology itself has been designed for use in a closed system rather than in place. Furthermore, its reliance on ultraviolet radiation limits action to exposed surfaces. This suggests little or no penetration of sediment deposits. As a consequence, the technology is not currently available for in-place use.

Biodegradation is one of the few natural mechanisms by which environmental residues may be transformed to less toxic residues. However laboratory and field studies indicate that this process is not operative to any significant extent with respect to PCB in sediments. Therefore, specially selected and cultured strains of microorganisms are required if biodegradation is to be achieved. Studies in Canada have identified strains capable of the desired activity on biphenyls with fewer than four chlorines. To date, these have been employed only in enclosed systems for wastewater treatment. Problems with in-place application and viability in an uncontrolled environment have not been resolved. Consequently, this option is not currently available for use.

Use of strong oxidizing agents has also been suggested as a means of degrading chlorinated hydrocarbons. Experimental work with specific agents has not been promising, however. As noted earlier, use of ozone alone was ineffective. Similarly, chlorine dioxide did not reduce residual levels of Kepone to any significant extent. While Kepone differs in structure from PCB, it displays similar characteristics in the environment and resistance to oxidation. This approach is also subject to the harshness and nonspecificity of oxidizing agents which would be required. These agents have significant environmental impacts of their own and have never been applied in an aquatic environment. Consequently, even if an effective agent can be identified for oxidizing PCB, the potential impacts and undeveloped stage of the technology militate against use in the open environment.

Both γ -radiation and electron beam radiation are capable of degrading complex organics. Exposure to the energy rich beams result in a step-wise breakdown in molecular structure. Work with γ sources has shown that sufficient doses can ultimately carbonize organic materials leaving no trace of the parent compound. More recent work with electron beams suggests that similar degradation can be achieved with this radiation scheme at lower doses. In disinfection studies with municipal sewage sludge, PCB content was found to be reduced significantly as an added benefit. The question of resultant by-products and their toxicity has not been resolved. This gives rise to some concern, since γ -radiation studies with Kepone revealed step-wise dechlorination. Hence, lower doses produced monohydrogen derivatives rather than completely dechlorinated structures. In addition, no attempt has been made to apply or test these approaches for use in place. Consequently, they are not available for implementation at this time.

Based on the above considerations, it is clear that no options with respect to in-place destruction of PCB are currently developed to a state which could be applied in Waukegan Harbor or the North Ditch. As a consequence, none of these approaches has been selected for detailed evaluation. It should be noted that these alternatives are not restricted to use in place. They may also apply to treatment of dredged residuals for destruction of PCB. This would allow disposal of the decontaminated spoils in a less restrictive (and less costly) manner. Once again, however, the technology has not been demonstrated on a sufficient scale or developed to a point where it could be applied to sediment slurries as a proven technology.

IN-PLACE FIXATION OR IMMOBILIZATION

The major hazard associated with persistent contaminants in aquatic sediments results from their transfer to the food web either directly or through dissolution in the water column. Consequently, destruction is not necessary to eliminate the environmental insult resulting from these contaminants if their availability can be reduced significantly. Three approaches to the reduction of availability have been evaluated as means of in-place toxic substances control: application of sorbents, placement of impermeable coverings, and in-place cementation.

Sorbents such as activated carbon have been employed to treat contamination stemming from soluble chemicals. More recently, it has been suggested that these or similar materials can be employed to reduce desorption from sediments. The functional principle involves partitioning of the contaminant (PCB in this case) between available physical and chemical phases. At equilibrium, PCB will approach concentrations in each phase such that they have a constant ratio,

$$\text{i.e., } \frac{\text{concentration in water}}{\text{concentration in solids}} = K \text{ constant.}$$

The value of the constant varies with the water quality and the nature of the solids. For instance, in the Hudson River, PCB was most concentrated in wood chips and related organic debris. Similarly, if sorbents are properly selected, PCB may have a stronger affinity for them than for the natural sediments. Hence, their presence in the system would reduce the availability of the contaminant and thus the subsequent ambient levels in the water column. Proof-of-principle experiments have been conducted with sorbents and Kepone, but the feasibility of large-scale application for PCB contamination has not been demonstrated. Data required for application and assessment of potential effectiveness as well as equipment for implementation are not currently available. Furthermore, several areas of contamination are sufficiently high that even with several orders of magnitude reduction in availability, sorbents would not reduce levels sufficiently. Consequently, the technology is insufficiently developed for use at this time.

The use of impermeable coverings to immobilize persistent contaminants was first evaluated for the EPA as a means of dealing with mercury deposits in sediments. The concept is based on placement of sheets of polymer film over the contaminated sediments to effectively block interchange of sediments and interstitial water with the water column. Hence, the reservoir of continuing inputs to the water and food chain is sealed off from contact. Because such films have a finite life in the environment, the immobilization achieved is temporary at best. Breakdown is accelerated if strong physical forces are present which would tear the film, e.g., large items of debris, strong currents, severe ice conditions, etc. This could be a particular concern in the Great Lakes area as a result of heavy boat traffic and winter freezing. These concerns would also prohibit future dredging in the sealed area. In the evaluation of seals for use in the James River, it was also determined that perforation would be necessary to

permit venting of gases formed in the underlying sediments as a result of anaerobic biological activity. Such perforation would also permit limited interchange of water above and below the seal and therefore would compromise its integrity. This realization coupled with the temporary nature of the approach militate against its use.

Chemical fixation involves technology developed for solidification and stabilization of wastes prior to disposal. Recently, this technology has been expanded for application in place. Of particular interest is work performed in Japan on in-place marine sediments. These studies, and ultimately field applications, were conducted using cementaceous or silicate based agents. To effect solidification, a mixture of Portland cement and proprietary reagents is added to the sediment mass. Lime stimulates the production of an insoluble silicon hydroxide matrix which entraps the sediment particles as it solidifies. Subsequent leaching is inhibited by the reduced porosity of the mass which restricts contact and movement. Development in Japan has focused on the design of equipment to mix reagents into in-place sediments and allow them to solidify. Full-scale application has been conducted both for production of stable foundations for construction and for immobilization of PCB-contaminated sediments. As a result, the technology is sufficiently developed to warrant further evaluation.

Since fixation can be applied both in place and on removed sediments prior to disposal, this technology offers two discrete alternatives for restoration. Costs and impacts differ between the two significantly.

Based on the above considerations, in-place fixation and fixation of dewatered sediments are deemed the only immobilization alternatives sufficiently well developed at this time to warrant detailed evaluation for use in Waukegan Harbor and the North Ditch.

REMOVAL AND DISPOSAL OF CONTAMINANTS

As noted previously, technology for application of fixatives in place is relatively new and, for the most part, remains in the conceptual stage. Much more work has been performed in the area of physical removal. Physical removal includes the most common approach to sediment problems, dredging, as well as more novel approaches such as retrievable sorbents, bioharvesting, use of oil-soaked mats, and solvent extraction. In all cases, removal is only the first step in the sequence and must be followed by some form of treatment and disposal.

Retrievable sorbents were evaluated for application in the James River (Kepone) and the Hudson River (PCB). This new concept is based on the ability of sorbents to concentrate contaminants from sediments and water. The sorbent particles are made retrievable by incorporation of magnetic particles in the media matrix. This renders them susceptible to collection with magnetic devices. They can therefore be spread over contaminated sediments, allowed to concentrate the contaminant, and then moved. Once

removed, the contaminants must still be destroyed or disposed of. While the approach has proven successful in bench-scale studies, it has not been applied in the field, nor has large-scale equipment been developed for implementation. Consequently, the technology is not currently available for application.

Biological harvesting has also been proposed for elimination of persistent contamination. This approach utilizes aquatic life to take up and concentrate contaminants in their tissue. Subsequently, the contaminant can be harvested with the life form and destroyed or disposed of. Advantage is therein gained since the biological form is selected to be more amenable to removal than the sediments. This approach is feasible with PCB as a result of its propensity to accumulate in the food chain. However, it is not practical. In mixed systems, PCB contamination resides largely in the sediments. Only small amounts of the total quantity are present in the water column. Harvestable biolife such as aquatic plants and fish take PCB up from water. Translocation into plants from soils and sediments was not observed in studies of Hudson River sediments. Hence, bioharvesting would be exceedingly slow since it would operate principally on PCB which has desorbed from sediments. The large reservoir of PCB present in the sediments would be harvested only after depletion of soluble PCB and subsequent desorption from sediments. Additionally, necessary equipment for harvesting has not been developed, let alone modified, for use in waters of the depth under review.

Investigators in the Hudson River studies evaluated the potential for using oil-soaked mats to concentrate PCB from sediments. This approach is similar in concept to use of retrievable sorbents in that it relies on application of a material with a high affinity for the contaminant in a form that is readily retrieved. As was the case with sorbents, the technology is conceptual at this stage and not developed to the state necessary for field application.

Solvent extraction has long been employed as a process for transferring materials from one chemical phase to another. It has also recently been considered for possible application in place as a means of extracting contaminants from sediments. Conceptually, the process would work much like retrievable sorbents. A lighter than water solvent with a high affinity for PCB would be selected. The solvent would be mixed with contaminated sediments at which time the PCB would desorb and enter the solvent phase. The solvent would then rise to the surface where it could be collected and removed. Such an effort has never been conducted in the field. Hence, answers are not available with respect to questions of contamination from solvent residuals, efficiency, and turbidity associated with mixing to a sediment depth of several feet. There is also concern that organic sediments will accumulate solvent and carry them back to the bottom after contact. Furthermore, many of the best solvents are also toxic. Until these potential problems can be addressed quantitatively, solvent extraction cannot be considered a viable alternative for application to in-place sediments.

Dredging

The most developed and widely used technology for control of contaminated sediments is physical removal via dredging or conventional excavations. This course of action is currently being recommended for remedy of PCB contamination of a 32 to 48 km (20 to 30 mi) stretch of the Hudson River. As such, dredging must be considered a prime candidate for reduction of contaminated sediments.

There are numerous options for specific dredging devices which must be considered if an implementation plan is to be selected. Raising the sediments from the bottom involves the use of marine dredging equipment. The process of dredging involves three basic steps: 1) loosening or dislodging the bottom sediments through mechanical penetration by a grabbing, raking, cutting or hydraulic scouring action; 2) lifting the dislodged sediment through use of mechanical devices such as buckets or by hydraulic suction; and 3) transportation of the dredged material by pipelines, scows, hopper dredges or trucks to a preselected treatment site.

Conventional dredges are not specifically designed or intended for use in recovering hazardous materials such as PCB resting on and in the bottom sediments of a watercourse, but may be considered a logical means to this end. The feasibility of this application is dependent upon local circumstances, but there is successful experience upon which to select viable dredging equipment and techniques.

The selection of a specific dredge type rests on a number of practical considerations:

- type and amount of sediments to be dredged
- physical and hydrological characteristics of the dredging site
- water depths in the area to be dredged
- dredged material disposal considerations
- availability of dredging equipment
- topographic limitations surrounding the dredge site
- water quality limitations imposed by beneficial water use
- costs.

These considerations apply to all normal types of dredging operations; however, since hazardous materials are involved in Waukegan Harbor additional factors must be considered:

- the need for precise determination and marking of boundaries in the area to be dredged
- the need for precise lateral and vertical control of the dredge head (for practical reasons only contaminated sediments should be dredged; over dredging compounds material handling, treating and final disposal problems)

- the need to predict the adverse impacts to aquatic and benthic organisms that can result from the dredging action, and the effect of each dredge type on resuspension of the pollutant into the water column
- the need to arrange for water column monitoring and to coordinate the local needs such as water filtration, navigation, etc.

The use of conventional and special purpose dredges to reduce the environmental degradation resulting from spills or discharges of heavier than water pollutants has become reliable. Experience has been reported from Japan since 1958 that contaminated sediments have been dredged from rivers, estuaries, harbors, and lakes with a high degree of success. The Japanese government, through its Bureau of Ports and Harbors of the Ministry of Transport, is sponsoring an extensive program of harbor restoration using dredges.

Specific experience in removing discharged PCB exists within the U.S. after an accidental discharge of 265 gallons of transformer fluid was effectively removed by a dredging operation conducted in the Duwamish River in Seattle, Washington. Also, the New York State Department of Environmental Conservation has instigated investigations, including a pilot operation, to reduce the concentration of PCB contaminants in the sediments of a 32 to 48 km (20 to 30 mi) stretch of the Upper Hudson River. Additional attention is being directed to the proper use of dredges for environmental restoration by the U.S. EPA Division of Marine Affairs. These combined experiences indicate that dredging is a viable and increasingly valuable restoration technique.

Dredge Types—

Currently available dredges can be divided into three categories: 1) mechanical and wireline, 2) hydraulic, and 3) pneumatic. Their operational techniques are discussed below.

Mechanical and Wireline Dredges--Mechanical and wireline dredges consist of the following types.

The clamshell dredge falls into the "wireline" category to the extent that a bi-parting bucket is lowered and raised by a hoisting cable. The bucket is lowered into the water body in an open mode, the weight of the bucket and the rate of descent causing it to sink into the bottom sediments. Through the medium of a cable reefing mechanism, the bucket is closed to take a "bite" out of the sediments. Once raised out of the water, the bucket is slowed around over a barge receiving the dredged material and the cabling is operated to open the bucket and dump its sediment content into the barge. This action is repeated until the barge is filled. Depending on the design of the barge, its sediment content can be bottom dumped at a predesignated underwater disposal site, or pumped as a slurry onto an onshore disposal site or landfill area.

The water quality can be degraded by this type of dredging operation and contaminated solids can be raised into water suspension by a number of

factors, e.g., the bucket's impact with the bottom sediments raises an extensive mud cloud, and the biting action into the sediments further disturbs bottom materials. During the ascent to the surface, the sediments froth and boil out of the bucket, a problem that increases with water depth. In deep water 23 m (75 ft) or more, up to 50% of the bucket's sediment content can be lost. Once the bucket is out of the water, a combination of water and dredging material (Figure 16) escapes during the slewing and dumping action. Material that sticks to the interior of the bucket is then washed out into the water body during the next descent. Since the bucket actually digs a pit into the bottom sediments, the sides of the pit slough, further degrading the water course. Some of these problems may be overcome by the clamshell bucket developed in Japan which is completely closed and sealed by flexible gaskets. There is no evidence that any of these are presently available in the U.S., however. The utilization of a water-tight bucket is known to generate 30 to 70% less turbidity in the water column, and the leakage of dredged material is reduced by approximately 35%. Depending on water movement, the "downstream" turbidity plume from a typical clamshell operation can extend for 300 m (1000 ft) at the surface and 500 m (1670 ft) near the bottom.

An additional operational problem is experienced using clamshells in attempting to determine or control the depth of the bottom cut. The dredge operator has little control of the penetration of the bucket into the bottom, especially if a free-fall action is permitted. As a direct result, uncontaminated sediments can be raised to the surface and must also be handled during treatment for the removal of contaminants. Normally an operator marks the hoisting/lowering cable to gain some knowledge of the depth of cut; however, unless the dredge is equipped with a swing gage, it is almost impossible to overlap each cut of the bucket and a broken windrow results on the bottom with mounds of contaminated earth left between each cut. To ensure bottom continuity, particularly in navigation channels, the operator swings the bucket on the bottom surface. This action obviously aggravates the problem of suspension by mixing contaminated sediments into the water column.

The dredge is productive about 40% of the operating time, and recovery of the bottom sediments is not continuous; at least 60% of the dredging time is spent raising, emptying, and lowering the clamshell bucket. Clamshell buckets range in capacity from 0.77 to 9.2 m³ (1 to 12 yd³) and 20 to 30 dump cycles/hr is typical. On this basis, an average 3.8 m³ (5 yd³) capacity bucket could dredge a maximum of 2800 m³ (3600 yd³) in a 24-hr workday. Clamshell dredging costs average \$3.27/m³ (\$2.50/yd³) in the Great Lakes area.

The dragline dredge is also classed as a wireline dredge. This unit tosses a bucket ahead of the dredge hull, then manipulates cables to draw the bucket across the sediments back toward the hull. Following a cut (closure of the bucket), the bucket is raised to the surface and slewed around over a "mud barge" where the dredged material is tipped into the barge by raising the bottom end of the bucket. The action is repeated continuously to complete the dredging project.

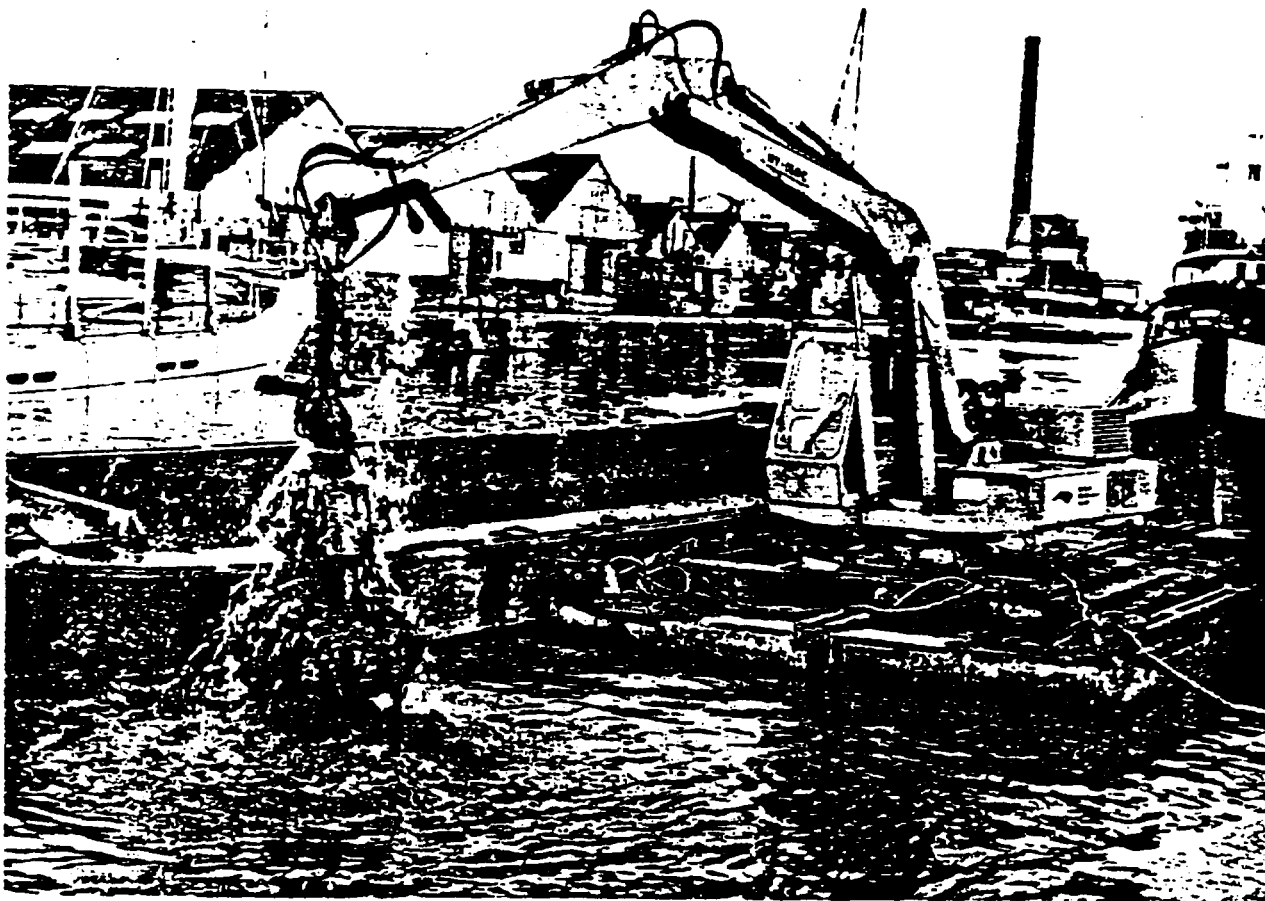


FIGURE 16. Hydraulically Operated Grab Dredge

(British Waterways Board) Reproduced with Permission, World Dredging and Marine Construction. Symcon Publishing Co., Vol. 11, No. 13, U.S. ISSN 0043-8405, December 1975.

All of the adverse environmental factors associated with the clamshell dredge would be applicable to the dragline dredge, i.e., mud clouds on bottom impact, trench sloughing, froth and boil-out during ascent, bucket leakage during the slewing action, and bucket surface wash during descent. Of greater importance is the fact that this type of dredge could not work within the confines of the Larsen Marine boat basin because of the action of the digging mechanism and bucket. The entry of a dredge, a mud barge and a maneuvering tug boat would not be practical in this area.

A dragline dredge having a normal 38 m^3 (5 yd^3) bucket could dredge 2300 m^3 (3000 yd^3) of material per 24 hr/day at a cost of $\$3.84/\text{m}^3$ ($\$2.94/\text{yd}^3$).

The dipper dredge (Figure 17) uses an articulated arm to scoop buckets full of sediments from the bottom. Its motion can best be described as that of an ice cream scoop. Once the bucket is raised out of the water and slewed around over a receiving barge, the bottom of the bucket is pulled open by a cable and the sediment content falls free into the hold of the barge. Some new dipper dredge units have replaced cable mechanisms and now use hydraulic systems to gain complete articulation and bucket operation. The adverse environmental/operating factors attributed to the other dredges in the mechanical category are repeated by this type of dredge and to some extent can be more severe as a result of the violent digging action involved.

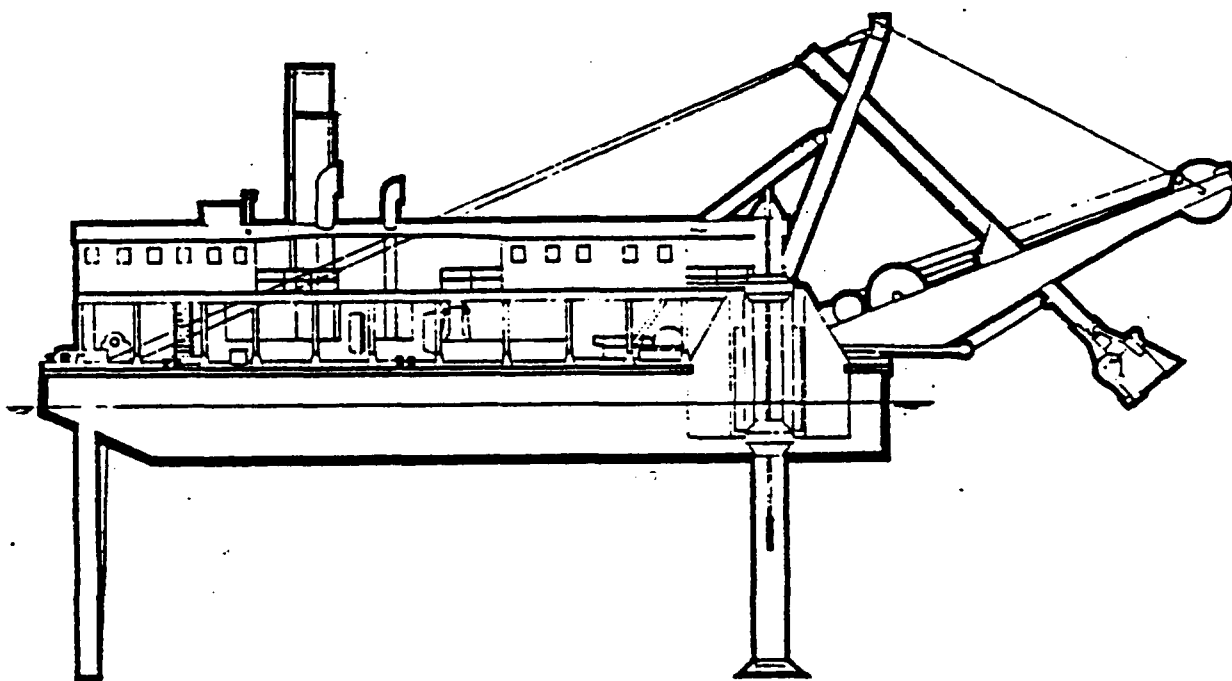


FIGURE 17. Basic Configuration of Dipper-Type Dredge
(Illustration Courtesy Bos Kalis Westminster Dredging Group)

As with other wireline/mechanical dredges the dipper dredges need spoil barge and tug support which would preclude its entry into a confined slip area. Dipper dredges have a bucket capacity range of 6 to 9 m³ (8 to 12 yd³) and operating cycles of 30/hr can be achieved. Cost estimates are based on an average 7.7 m³ (10 yd³) dredge operating at 30 cycles/hr to dredge 1800 m³ (2400 yd³) per 24 hr/day at \$3.27/m³ (\$2.50/yd³).

Although the bucket ladder dredge (Figure 18) is used extensively in Europe, there are few of these dredges in the U.S., where they are used for the mining and recovery of sand and gravel aggregates. One unit is known to be dredging for gold in California. The principle of operation involves a continuous line of buckets passing over a hinged ladder. Once the ladder is lowered to the bottom, each bucket digs into the sediments and transports the content to the surface. There it is transferred to a sideloading conveyor or chute which feeds the dredged material to a receiving barge or vessel moored alongside the dredge. Many of the adverse environmental considerations previously discussed apply to this system. The units are noisy in operation, greatly agitate the bottom sediments, and the buckets dewater once above water level; froth and boilout also occur during the ascent to the surface. Even if available, the use of such a dredge to recover polluted bottom sediments would have an adverse impact on the water quality and would result in dispersion of the contaminants over a wide area. It is largely for this reason that this type of dredge is becoming obsolete in the U.S.

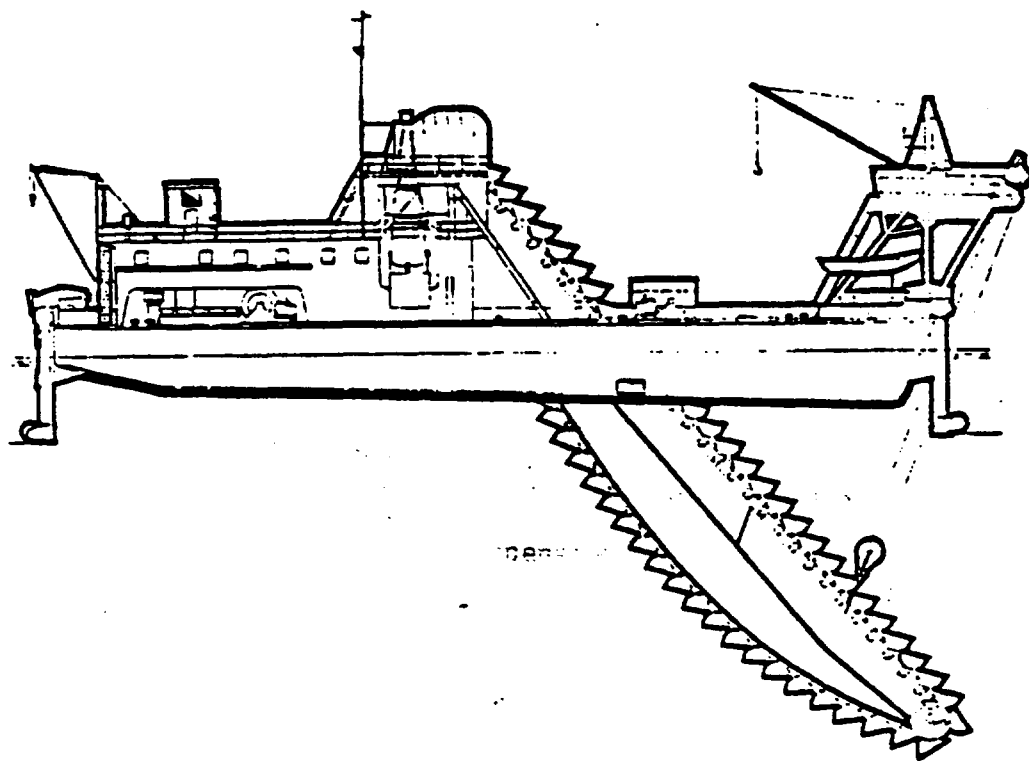


FIGURE 18. Bucket Ladder Dredge

(Illustration Courtesy Bos Kalis Westminster Dredging Group)

Because this equipment is limited in supply, and is presently dedicated to private mining operations, such a unit would not be available for application in Waukegan.

Hydraulic Dredges—There are a variety of hydraulic dredges. The basis of operation involves a suction line, a centrifugal suction pump, and a discharge line which is normally borne on a series of pontoon floats. It is possible, however, to submerge the discharge line under the water to permit free navigation in shipping channels. The discharge line can be extended to any desired length and pumping can be accommodated by installing booster pumps to assist the main, on-board centrifugal pump. In effect, the pump discharge provides "built in" transportation of the dredged material. Table 2 describes the basic characteristics of a variety of dredges.

The hopper dredge is a self-contained, self-propelled, ship-shaped vessel that uses an onboard suction pump to draw bottom sediments through a suction head and pipe which trails at the side of the dredge (Figure 19). Until recently, the Corps of Engineers owned and operated all hopper dredges in the U.S. However, private industry has built some hopper dredges which now are available for private dredging contracts.

In this operation, the dredged material is drawn into the ship within which it accumulates in large hopper compartments. Normal operation involved filling the hoppers with sediments, which by accumulation and gravitational settling displaced the water through a series of overboard discharges. Once the hoppers were filled to a load limit the dredge would proceed out to sea or to a designated dump area, open dump doors in the lowermost hull section and thereby offload the dredged sediments. The practice of permitting water overflow through discharge openings results in fine solids passing freely into the watercourse where long-range turbidity problems may develop. To control this, overboard water discharges have been prohibited by State authority in certain parts of the nation (Delaware River; Hampton Roads, Virginia, and probably other areas). As a result of this prohibition the vessels, when fully laden, have a high water-to-solid ratio. They proceed to specially prepared locations, connect onto a discharge connection and pump the water-laden dredge spoil to an on-land disposal site.

The large size and operating speed (13 km/hr) of the hopper dredges demand extensive maneuvering space and therefore preclude the use of this type of dredge in the confines of a small-contaminated harbor. Therefore, no time and cost estimates are provided on these units. It should be mentioned, however, that the Corps uses a hopper dredge to conduct maintenance dredging of the main entrance channel into Waukegan Harbor. The frequency of the dredging is dependent on the shoaling rate, but an average of 27,000 m³/yr (35,000 yd³/yr) are dredged and dumped into the open lake. Since discovery of the PCB contamination, no maintenance dredging has been undertaken by the Corps.

TABLE 2. Specifications for Typical Dredges of Various Types

Type Dredge	Pipeline Diameter In. (x 2.54-cm)	Weight Tons (x 1.1-tonnes)	Length ft (x 0.305-m)	Width ft (x 0.305-m)	Weight ft (x 0.305-m)	Draft in. (x 2.54-cm)	Freeboard in. (x 2.54-cm)	No.	Dredge Plant hp (x 0.746-kw)	Sigs	Drive	Production Rate cu meter (x 0.305-m)	Dredging Depth ft (x 0.305-m)	Single Pass Excavation lb (x 0.454-kg)	Remarks
Dredge	32	..	266	50	60	60	48	1	2100	38	Steam	3500	65	65	
Cutterhead/Section	6	18.5	66	16	28	34	14	1	175	8	Diesel	26.35	11	18	Portable
Cutterhead/Section	8	12.5	44	11	28	35	13	1	176	8	Diesel	45.106	22	18	Portable
Cutterhead/Section	10	12.5	60	17	33	42	17	1	336	12	Diesel	82.370	25	18	
Cutterhead/Section	13	23.5	60	23	33	42	16	1	520	14	Diesel	127.810	35	18	
Cutterhead/Section	14	67	96	28	33	43	17	1	520	16	Diesel	160.103	26	21	
Cutterhead/Section	14	166	130	29	55	56	17	1	1126	19	Diesel	241.575	40	21	
Cutterhead/Section	25	316	130	32	70	64	62	1	1700	26	Diesel	213.1195	50	24	
Cutterhead/Section	21	374	135	32	70	66	40	1	2250	26	Diesel	815.1916	50	30	
Cutterhead/Section	33	358	225	36	87	60	36	1	3600	30	Diesel	576.1300	50	35	
Pneumatic	8	13	115	32	82	63	23	3	720	NA	Diesel	60.390	65	39	Portable
Hydraulic	4	13.5	30	8	5	18	12	1	173	4	Diesel	65.150	15	16	Portable

From: U.S. Corps of Engineers Draft Report to the U.S. Coast Guard, "A Feasibility Study of Response Techniques for Discharges of Hazardous Chemicals That Sink" (1978).

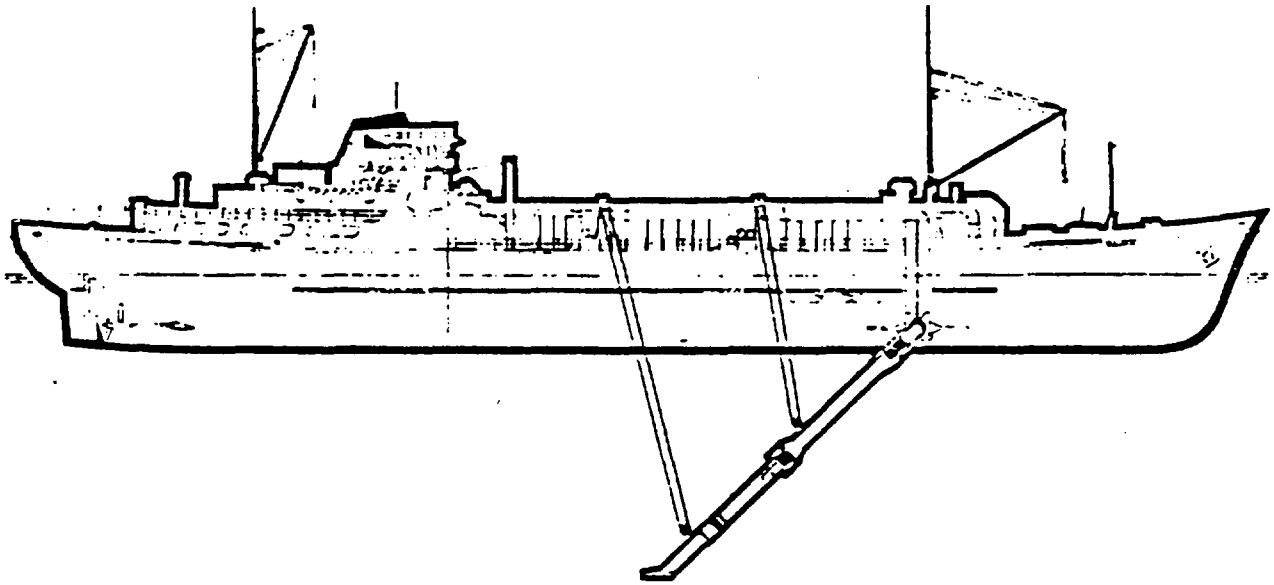


FIGURE 19. Suction Hopper Dredge

(Illustration Courtesy Bos Kalis Westminster Dredging Group)

The cutterhead pipeline suction dredge is not self-propelled, but utilizes tugs for onsite positioning, then uses widespread anchors to winch forward with the aid of "walking spuds". A rotating cutterhead scarifies the sediments to facilitate sediment travel into the suction intake. The material passes through the suction pump and is discharged through a floating pontoon-supported discharge line. The suction line can vary from 15 cm (6 in.) to as much as 105 cm (42 in.) in diameter. The dredge normally cuts a trench in the bottom sediments. However, a lateral swing action to either side of the dredge centerline results in a fairly wide dredging swath being cut through the sediments. In soft unconsolidated sediments the units can operate with the cutterhead inoperative or completely removed (Figure 20). To minimize turbulent sediment boiling in a heavily polluted area, such as Waukegan Harbor, this procedure would be necessary to protect the water quality.

This type of dredge even without the cutterhead can still raise some bottom soil into water suspension, although most of the dredge material is drawn into the suction pipe. Investigations into the nature, degree, and extent of dredged material dispersion around a cutterhead dredge, with the cutterhead in an operational mode, indicate that the material raised into suspension is localized in the immediate vicinity of the swinging, rotating, cutterhead. Within 3 m (10 ft) of the cutter, suspended solids are highly variable but may be as high as a few tens of grams per liter; these

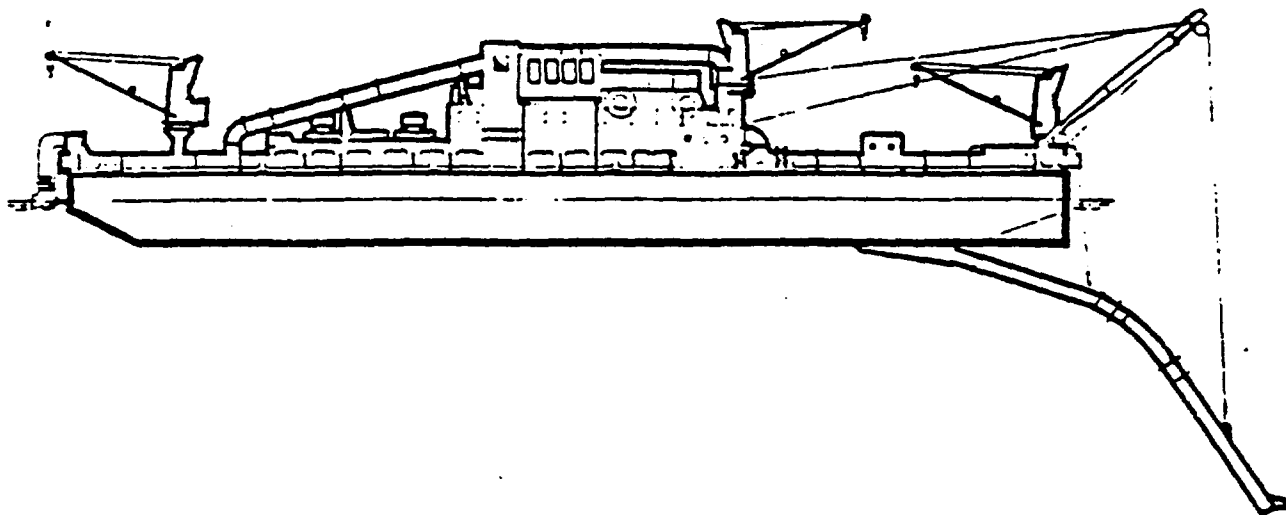


FIGURE 20. Hydraulic Pipeline Suction Dredge (Without Cutterhead)

(Illustration Courtesy Bos Kalis Westminster Dredging Group)

concentrations decrease exponentially with distance from the cutter to the water surface. Near bottom, suspended solids concentrations may be elevated to levels of a few hundred milligrams per liter at distances of a few hundred meters from the cutter. Turbidity levels generated around the cutter increase exponentially as the thickness of the cut, rate of swing, and the cutter rotation rate is increased. Although suspended solids levels around the cutter increase with increasing rates of production, it is possible to maximize the production rate of the dredge without resuspending excessive amounts of bottom sediment. This result would, to a great extent, be controlled by removal of the cutterhead. Additional means of turbidity control are described later in the report.

The continual dropping of anchors and the use of tugs for dredge movement can adversely impact water quality at the dredge site through suspension of sediments. The bottom disturbances from tug operation is caused by propeller action in shallow waters and other effects of repositioning the dredge. The size of the tug and dredging system has a direct bearing on adverse environmental impact control. The production capacity of a 25.4 cm (10 in.) pipeline dredge could be expected to range to a maximum of 5500 m³ (7200 yd³) per 24 hr/day. The cost per cubic yard is in the vicinity of \$2.00/m³ (\$1.50/yd³). However, mobilization and demobilization costs could raise the price to as much as \$5.20/m³ (\$4.00/yd³) for small volume jobs.

The dustpan dredge is a self-propelled, hydraulic suction pipeline dredge. The suction head is shaped like a large dustpan and has scarification water jets fitted along the leading edge of the intake. The suction head, suction line, and water jet line are mounted on a structural ladder hinged in a well section located in the forward part of the dredge.

The ladder is raised and lowered by winch cables, thereby providing very precise control over the depth of dredging cut. The suction head is pulled into the material by winches taking in two cables that run upstream to anchors set above the cut area.

When required, the material is agitated or loosened by the water jets, then drawn into the suction head, and pumped through a floating discharge line to a spoil disposal area. The dredge operates with a low-head, high-capacity pump as the material is raised only a few feet above the water surface and the discharge line can be 240 to 300 m (800 to 1000 ft) long. During operations in river dredging the discharge is normally pumped from the midstream-channel towards the banks of the river; the discharge line is held away from the dredge by the force developed from effluent discharging against a terminal baffle plate mounted at the end of the discharge line. The line is maneuvered to the desired location by changing the angle of the terminal baffle plates. Under normal operation the dustpan suction head on this type of dredge is capable of cutting a depth controlled swath of up to 11 m (36 ft) wide through the bottom sediments.

The only dustpan dredges in the U.S. are owned by the Corps of Engineers, who can use the vessels for dredging polluted sediments when not involved in navigational channel dredging. The Corps' St. Louis District was contacted to determine the availability of a dustpan dredge for use in the open Waukegan Harbor and Slips 1 and 3. It was discovered that even with a hinged smoke stack the Corps dredges could not navigate a low bridge and a lock that restricts river access into the Great Lakes area. One of the Corps' dustpan dredges, "Black", has become excess to the needs of the U.S. Army and will probably be given as surplus property to an historical society. The dustpan suction head from this dredge could be temporarily removed and loaned for use on the Waukegan Harbor project, with the dredger assuming the cost of suction head removal, shipment and fabricated attachment to a conventional hydraulic pipeline dredge. Unfortunately, the dimensions and configurations of the suction head 11 m wide, 3 m deep with double 61 cm diameter suctions (36 ft by 10 ft, 24 in. diameter) could not be fitted to any of the hydraulic dredges currently available in the Great Lakes area. (a)

It is possible that a conventional hydraulic dredge could be equipped with a dustpan suction head of limited size for the recovery of contaminated bottom sediments. Once equipped the dredge would, in every probability, be the best suited for the recovery of unconsolidated sediments at a predetermined depth of contamination. Such a dredge would be the least likely to raise the sediments into suspension in the water column. This concept is discussed later in this report.

(a) The large industrial dredges are currently involved in foreign dredging contracts.

The Mud Cat dredge (Figure 21), which is of limited dimension, is available for lease from the Mud Cat Division of the National Car Rental System, Inc. It can be drawn from a large fleet of units (250) strategically located around the nation. The vessels are transported to the dredge site on a flatbed truck from which they are launched into the watercourse. The dredges are 12 m (39 ft) long and 2.4 m (8 ft) wide. Forward propulsion is gained by winching on a cable connected to trees on the riverbank or to "deadman" anchors. The principle of operation involves a horizontal screw auger mounted on the end of the hydraulically operated boom. The auger is designed in two halves that operate in opposite directions feeding the bottom sediments to a center suction. The augers are equipped with a series of cutter-knives distributed around the auger flight. These knives dislodge and cut the material in a scissor-like action. The unit has the capability of dredging to a depth of 3 to 4.5 m (10 to 15 ft) and cuts a 2.4 m (8 ft) swath on the bottom. A mud shield or shroud can be hydraulically lowered over the augers to entrap the dredged material and minimize turbidity during the dredging operation. Silt and water recovered from the bottom then passes through a "rock box" to trap rock and other debris, then through a centrifugal pump to a 20 cm (8 in.) discharge line which floats on the water surface and transports the dredged material to a preselected disposal or treatment site. The pumping distance can be greatly extended, as with all hydraulic dredges, by the utilization of booster pumps at strategic locations in the discharge line.

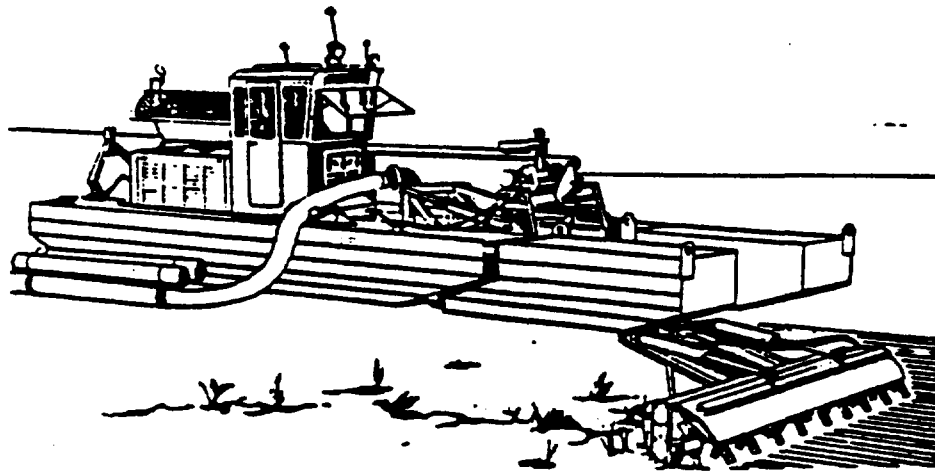


FIGURE 21. Mud Cat Dredge

(Illustration Courtesy Mud Cat National Car Rental System, Inc.)

This type of dredge does not have the capability of working in deep waters, since the maximum dredging depth is established at 4.5 m (15 ft). It is capable of removing sediments at a rate of 31 m^3 ($40 \text{ yd}^3/\text{hr}$) and must be leased for a minimum of 2 months. Total costs for that period are estimated at \$44,300 and on the basis of 60 days at 24 hr/day, this constitutes a unit charge of \$2.35 to $2.61/\text{m}^3$ (\$1.80 to $2.00/\text{yd}^3$). Assuming 20% downtime, final unit costs would average $\$3.14/\text{m}^3$ ($\$2.40/\text{yd}^3$).

The sidecaster dredge duplicates the hopper dredge with the exception that the dredged material is cast overboard from either side of the vessel by means of a sidecasting boom that has 180 degrees of swing to permit a port or a starboard discharge from the dredge. There are only three known dredges of this type in the U.S. All three are owned by the Corps of Engineers (although the Corps' hopper dredge, "McFarland", is equipped with sidecasting capabilities). The sidecaster dredges owned by the Corps are actually seagoing vessels which, when in operation, "throw" the dredged material well clear of the dredge area through discharge pipes ranging from 21.4 to 31 m (70 to 100 ft) long, depending on the dredge. The self-propelled vessels were designed by the Corps using U.S. Navy hulls as indicated in Table 3.

They are being used along the East Coast (mostly in the mid-Atlantic coastal region) for maintaining narrow inlets exposed to the open sea. These projects are relatively small (in volume) and thus do not require the higher-production hopper dredges, as long as the dredged material can be discharged back into the water body clear of the actual shipping channel. The Corps claims an average dredge production rate of $252 \text{ m}^3/\text{hr}$ ($330 \text{ yd}^3/\text{hr}$) or $5965 \text{ m}^3/\text{day}$ ($7928 \text{ yd}^3/\text{day}$) at a cost of about $\$1.70/\text{m}^3$ ($\$1.30/\text{yd}^3$). This is, however, an unsubstantiated figure since the vessels lack instrumentation to verify the pumping rate and shoreside logistics are not included in the costing.

Sidecast dredging is basically a process for digging material from one place and depositing it in another location clear of the digging area. The bottom sediments are disturbed in the digging area by passing the draghead across the bottom, sloughing the sides of the dredged trench, and eventually sloughing the sides of the channel. This is followed by a $252 \text{ m}^3/\text{hr}$ ($330 \text{ yd}^3/\text{hr}$) discharge of solids back into the watercourse, where the sediments degrade water clarity until they resettle on the bottom. There is no possible way of improving the environmental situation and still use the dredge in its design mode. The Corps compares the environmental disadvantages to the need to maintain economically shallow navigational channels to accommodate barges, fishing fleets, shallow-draft coastal vessels, and pleasure craft.

As a result of environmental concern about sidecasting operations (mainly over turbidity in shallow water), the Corps has been experimenting with a bottom-dump barge used in conjunction with a sidecaster. Essentially, this concept involves loading the barge with the sidecasting

TABLE 3. Basic Data on the U.S. Army Corps of Engineers Sidecaster Dredges

Dredge Year Built	Sidecaster Boom		Dredge Pumps		Propulsion		Maximum Dredge Depth (X 0.305 = m)	Hull			Vertical Clearance Req'd (X 0.305 = m)
	Lgth. (X 0.305 = m)	Dia. (X 0.305 = m)	No. HP	Size Type	No. HP	Type		Lgth. (X 2.54 = cm)	Beam (X 2.54 = cm)	Draft (X 2.54 = cm)	
FRY(YSD)(a) 1972	70'	14"	1 324	12" diesel	2 360	diesel	20'	104.'0"	30.'0"	4'6"	32'7"
Merritt(a) (1964) (YSD)	80'	12"	1 340	12" diesel	2 340	diesel	20'	104.'0"	30.'0"	4'9"	28'5"
Schweizer(b) (1966) (YF)	100'	16"	2	12"	2 350	diesel	25'	133.'7"	30.'0"	8'6"	51'6"

(a) USN Seaplane Wrecking Derrick (self-propelled)
(b) YF USN Covered Lighter (self-propelled)

boom and hauling the spoil to deeper water (designated spoil site) where it is dumped. The particular barge design being tested is one in which the hull splits longitudinally in two (hinged at the top) to permit rapid dumping. Such a barge might also be useful in transporting dredged material (consisting of beach sand in many projects) close enough to a nearby beach to nourish the beach.

Sidecaster dredges could not be adapted to polluted sediment dredging for a number of reasons:

- The method of dredge spoil disposal back into the waterbody would greatly compound the pollution problem.
- The vessels need considerable maneuvering space that is not available within a confined harbor.
- When working close to land the discharge would actually be cast onto the land mass.
- The vessels must hold a speed of about 3 knots to maintain steerage, which in itself develops problems within a confined harbor, since the vessels vary in length from 32 to 41 m (104 to 134 ft).
- The present Federal demand for the sidecaster units would not release them for other assignments such as the Waukegan Harbor project.

Pneumatic dredges—Three types of pneumatic dredges were evaluated.

The airlift dredge (Figures 22 and 23) is generally fabricated for a specific purpose, and does not fall into a category of stock or off-the-shelf dredging units. The airlift is a dredging system that consists principally of a partially submerged vertical-recovery pipe into which compressed air is injected at a point below the water surface (the units are more efficient in deep rather than shallow water). The process of the buoyant air rising to the surface inside the recovery pipe causes the air-water mixture to overflow from the surface end of the pipe, due to the density reduction in the upper pipe section and the hydraulic head of water outside the pipe, resulting in a high-velocity flow into the base of the pipe. As the water flows into the submerged end of the recovery pipe (which is positioned as close to the bottom as practical), the inrush of water picks up and transports the bottom sediments through the pipe to the surface where the solid/water mixture is discharged into a recovery barge. The flow can be characterized as two-phase (water and solid) below the air-injection point and three-phase (water, air, and solids) above the air-injection point. The principle is similar to vacuuming the bottom, and most of the sediments raised from the bottom are drawn directly into the intake of the recovery pipe, markedly controlling turbidity.

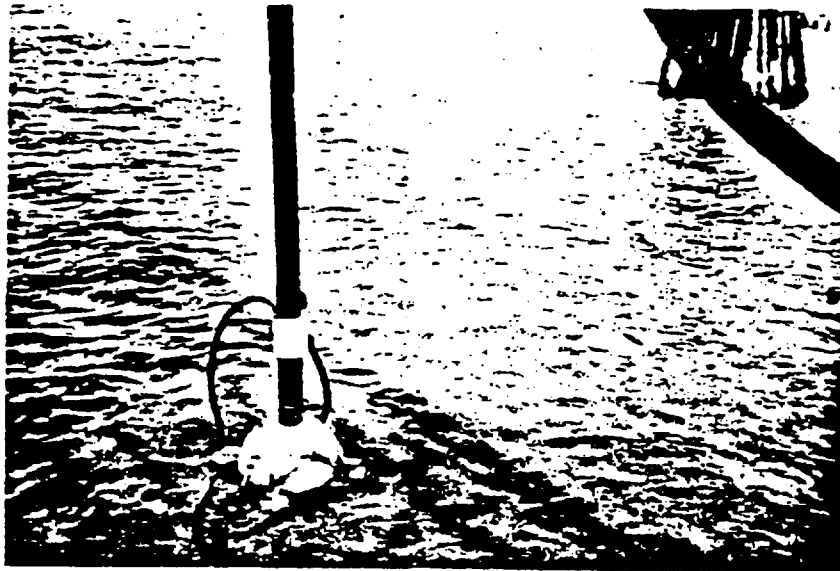


FIGURE 22a. Airlift System Using Flexible Suction Line

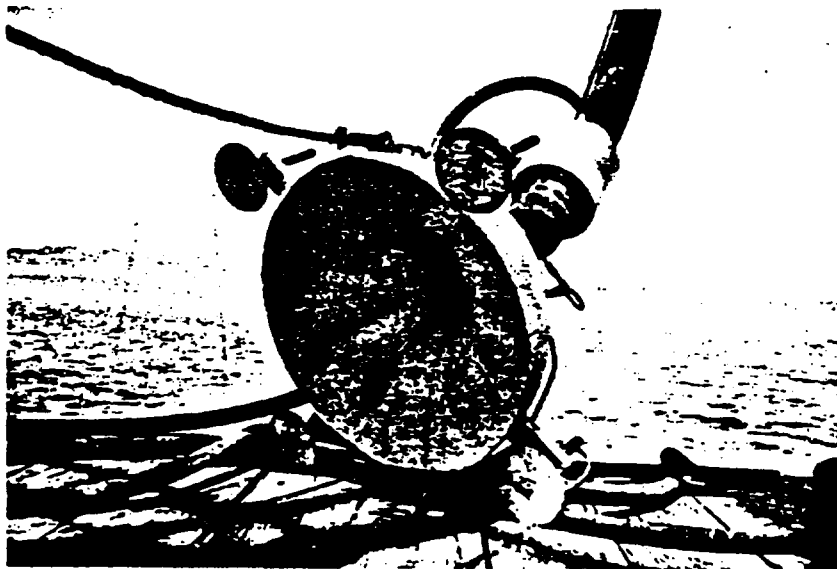


FIGURE 22b. Suction Head Designed with "Trumpet" Throat

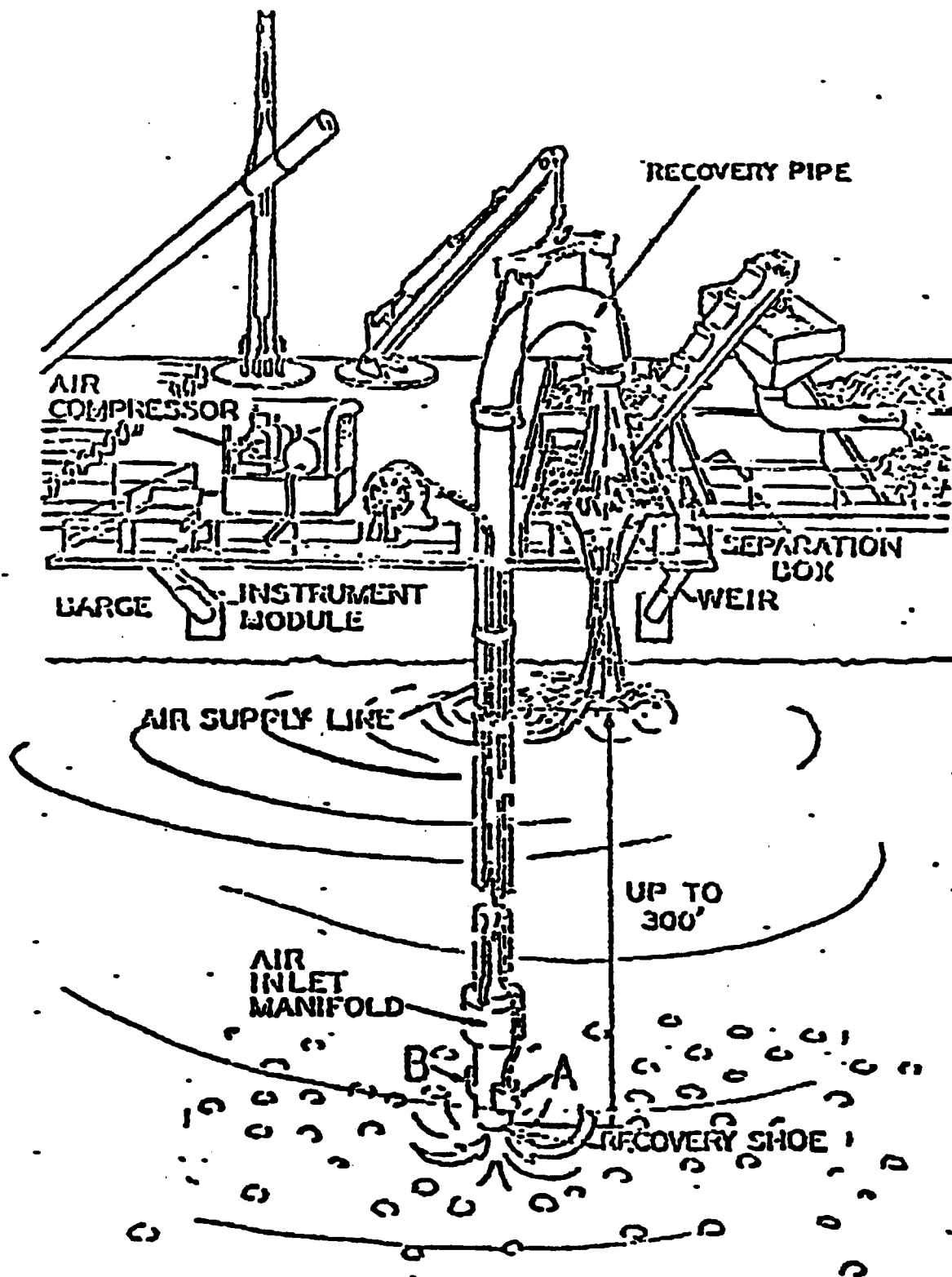


FIGURE 23. Conceptual Airlift Dredging System
(U.S. Bureau of Mines)

The operating efficiency of an airlift is a variable that ranges from 30 to 62% based on the design of the system. Operational problems that are encountered include air compression and transmission losses, pipe friction and air slippage through water. Water slippage around the solids in water suspension can also affect the operating efficiency.

Data exist on the throughput of solids by means of an airlift system; this is again a wide variable based on design factors. The percent solid-to-water ratio has been monitored from 15% to a high of 70%. Considerable empirical data exist on the flow of fluids through recovery pipes of various diameters. Ideally, the velocity should be sufficient to keep up with the rate of ascent of the largest bubbles injected into the recovery pipe to keep the solid materials from settling.

There are a number of formulas for calculating optimal recovery pipe diameter. Too small a diameter will result in excessive friction, while too large a diameter will encourage air slippage. In brief, the area of the recovery/discharge pipe should equal the discharge rate in gpm divided by a factor of 12 to 15.

Formula are also available for calculating the optimal air supply line diameter, depending on the quantity and velocity of flow required. Tests indicate that an air velocity, in the air supply line, of 9.2 to 12.2 m/sec (30 to 40 ft/sec) develops a productive air supply. There appears to be a minimum diameter of air supply line below which friction losses increase rapidly. Studies suggest the use of a 5 cm (2 in.) air supply line for a 15 cm (6 in.) recovery pipe, a 6.8 cm (2-1/2 in.) line for a 20.3 cm (8 in.) recovery pipe and probably a 7.5 cm (3 in.) diameter air supply for a 25 cm (10 in.) diameter dredging system. The productivity of an airlift dredge can be increased if small bubble air streams are injected into the recovery pipe. Preliminary tests show that small bubbles have a lower slip velocity than larger bubbles which are too buoyant and thus "leave the water behind". The injection of air through sintered brass or bronze having about 60% the density of the parent metal produces the desirable bubble size.

The rate of air flow is an important factor with respect to dredge production - test data indicate that excessive air flow produces friction and air waste while limited air flow causes surging and reduced yield. The optimal rate of air flow ranges at six to eight times the rate of flow required to initiate water flow through the recovery pipe.

The major problem with airlift operation involves the need to develop a swing action. Otherwise, the dredge will only excavate the sediments directly below the suction; in effect, cratering will occur. For this reason, to gain maximum coverage, the unit should be supported by a conventional dredge that can use widely spaced anchors and walking spuds to gain lateral movement.

It does not appear practical that the services of a hydraulic dredge should be retained and modified to support an airlift suction system. In a similar manner the design and fabrication of an airlift dredging system,

which would require mud barges for transportation to the sediment treatment/disposal site, would not be cost beneficial for use on the Waukegan project.

There are, however, some dredges which utilize a somewhat modified airlift approach to the dredging process.

The Pneuma dredge, Italian-designed and patented, operates, in most respects, on the principle of an airlift (Figure 24). The system is based on utilization of the static water head and compressed air, which is supplied to the lowermost head to develop a continuous flow of water through the pipe, with the velocity of water entering the suction pipe carrying solids in the upward stream. The dredging head or chamber is emptied through use of compressed air which drives the chamber's content out through the discharge line. Subsequently the pressure is brought back to atmospheric levels and the parts opened. The hydraulic head of the water column forces water into the chamber to equalize the pressure. Sediments are carried in with the onrushing water and hence enter the chamber. The parts are then closed and pumped out with compressed air to begin the cycle again. With several heads operated in off-set sequence, the net action is one of continuous pumping.

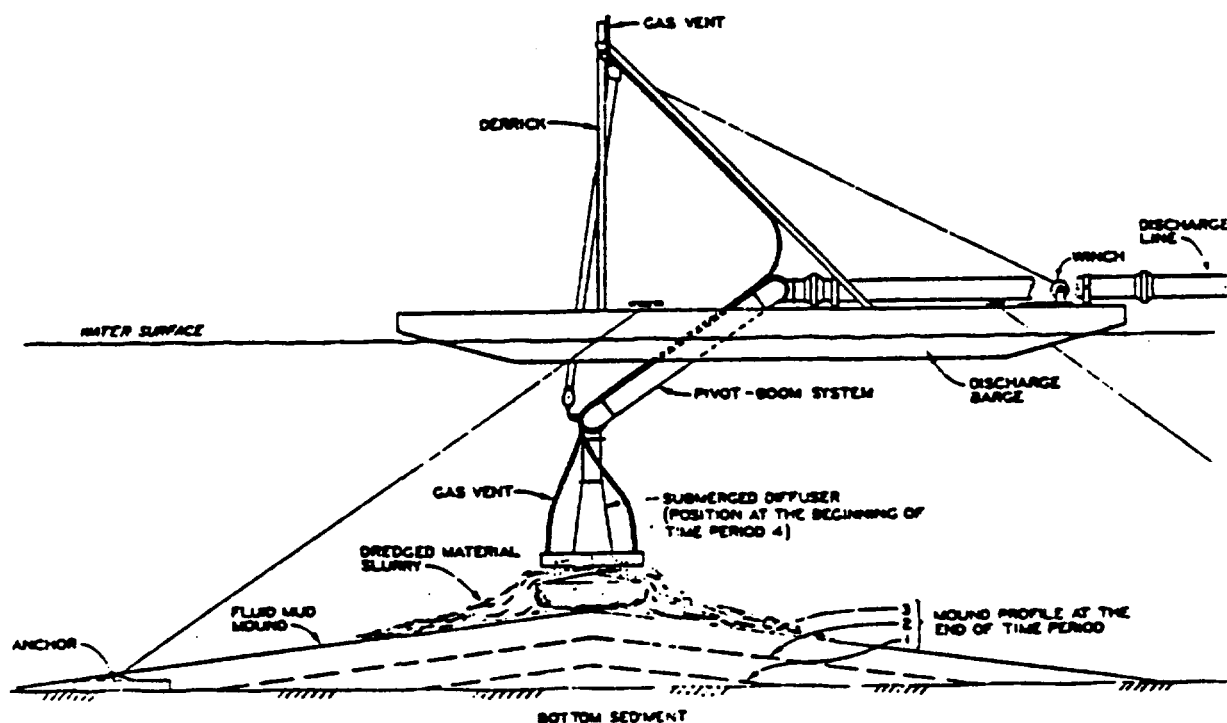


FIGURE 24. Conceptual Design of Pneuma Dredge

As previously described, this unit has already been used to dredge PCB-contaminated sediments from a water body in the State of Washington. On that project the dredge's pumping rate was established at 12 to 155,000 m³ (15 to 20,000 yd³) during a 30-day period, the first time the Pneuma had been used for polluted sediment dredging in the U.S. and the only source of documentation on its use here. The dredge operated on only an 8-hr day basis, developing a direct dredging cost of \$108,688. Operations were often halted due to clogging and stoppage from debris on the river bottom. Under clear conditions, the removal rate could be expected to be higher. As far as can be determined at this time, the Pneuma Dredge (pump, distributor, shovels and hosing) leases for \$500/day and requires a crew of three at an additional cost of \$450.00/day for a 10-hr work day, in which 8 hr of actual dredging would be undertaken at an hourly production rate of 300 to 375 m³ (400 to 500 yd³). One of the three crew members is a technician supplied by Pneuma. Mobilization costs and the cost for barge rental are additional.

The Oozer dredge (Figure 25) is patented by the Japanese government and currently none are operational within the U.S. One U.S. representative for the Japanese concern licensed to operate the dredge (TJK, Inc., of North Hollywood, California) states that it would cost about \$40,000 to bring the necessary Oozer pumps and parts to the West Coast of the United States from Japan. However, when a project becomes imminent, TJK, Inc., plans to consummate a joint venture with an American company in order to provide full capabilities regardless of the requirement. U.S. Federal law presently places restrictions on the entry and use of foreign dredges and dredge equipment in this country. Use of this dredge within the U.S. would have to be allowed under a special circumstance or test process with the U.S. Bureau of Customs and the U.S. Coast Guard being the decision-making bodies. Engineers with the Corps in Norfolk, Virginia, have viewed the Oozer dredge in operation and speak highly of its capabilities and its effectiveness in controlling turbidity.

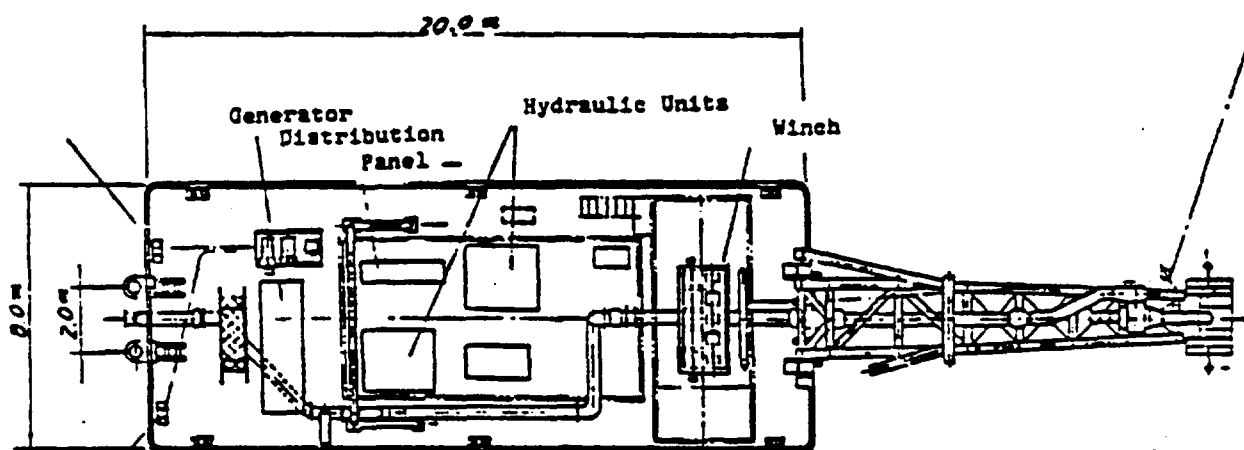


FIGURE 25. Typical Configuration of Oozer Dredge

The unit operates on the combined principles of vacuum and water pressure and has a number of suction head designs suited to a variety of bottom sediments. The dredging capacity of the unit, when pumping over a distance of 900 m (3000 ft), is in the range of 2400 m³/day (3144 yd³/day). (This may be increased by the provision of one or more booster pumps). Personnel of the Norfolk Corps of Engineers, who have viewed this pump in operation state that the operating cost per cubic yard is in the vicinity of \$3.54, whereas the Project Director of the Machinery Division of Marubeni American Corporation, as the Oozer dredge representative in New York, states that \$5.3 to 6.6/m³ (\$4 to 5/yd³) would be a more likely cost. A unit rate of \$6/m³ (\$4.50/yd³) has been employed herein for estimation purposes.

Summary—Based on the above discussion, six types of dredges may be available and feasible for use in a small harbor area: 1) clamshell, 2) dragline, 3) dipper, 4) hydraulic pipeline, 5) Pneuma, and 6) Oozer. Selection of the most appropriate must be based on the specific area to be addressed.

Excavation

Excavation technology is commonly employed for any kind of subsurface work and can involve anything from manual use of pick and shovel to application of sophisticated mechanical equipment such as backhoes and articulated steam shovels. When ground-water flows are intercepted, as is the case in Waukegan, permeability barriers may be required along with temporary shoring. For these applications, open cut techniques used for utilities are preferable. Specifics will vary with location of the work. Water intrusion control technology is familiar to contractors in the Waukegan area since sewer lines must often be placed in areas with similar ground-water levels.

The major determinants with respect to excavation techniques as an alternative to dredging rests with the ability to exclude waters from the area of removal. The degree to which this can be accomplished will, to a certain extent, determine the type of equipment that can be employed. For instance, if the excavation site can be completely dried, it will support conventional roadway equipment, and removal can be accomplished with scrapers, front loaders and other wheeled vehicles operating on the soil surface as well as with manual labor. If, however, the site cannot be dewatered to that extent, more sophisticated equipment will be required operating from firmer ground to the side of the excavation. Candidate machinery would include backhoes, articulated steam shovels, and dragline cranes.

The exclusion of water from the excavation site can be accomplished in several ways. Surface waters can be intercepted with cofferdam structures and intrusion countered with a battery of pumps. Ground-water seepage can be stopped through use of well points and pumps. In this case, pumped wells

are employed to export water from the site at a higher rate than it can be replenished. This leads to draw down in the vicinity of the well and a commensurate drop in the water table to a level below that of excavation. Ground water can also be excluded from a site through injection of grouts. These polymeric materials form long chain molecules which bind the soil particles together in an impermeable mass. This eventually creates an in-place cofferdam around and under the excavation site.

If excavation is to be taken to a depth of more than several feet, safety considerations as prescribed by the Occupational Safety and Health Administration (OSHA) require either temporary shoring or maintenance of a maximum slope of 1:1 on the walls or less. When shoring is temporary, backfill is necessary to replace it.

Impacts resulting from excavation are largely those associated with construction projects: noise and dust. The need for continuous removal of excavated soils will also stimulate a heavy increase of traffic in the local area. If surface pumps or well points are employed, pumped water will likely carry dissolved and particulate contaminations and hence must be routed to a treatment facility.

Contact with construction firms in the local Waukegan area has confirmed the capability to undertake a full variety of excavation activities. Therefore, excavation must be considered a candidate approach to reduction of contamination.

Should dredging or excavation be selected for Waukegan Harbor or the North Ditch, it will give rise to the associated need for supernatant treatment and ultimate disposal of spoils. Therefore, alternatives for these operations must also be considered.

Supernatant Treatment

While relatively insoluble, PCB will partition between the water and solids phase. Hence, supernatant water from dredge spoils will carry both PCB attached to suspended matter and dissolved PCB. The desired level of residual PCB in water will dictate the type and degree of treatment required. To date, five approaches have been employed or evaluated for similar applications: 1) flocculation-sedimentation, 2) flocculation-sedimentation with sand filtration, 3) flocculation-sedimentation with carbon adsorption, 4) powdered carbon adsorption, 5) catalytic reduction, and 6) UV/ozonolysis. The predominance of PCB associated with particulate matter in aquatic systems renders treatment aimed at solids removal effective for PCB reduction. Researchers at Michigan State University found a relatively constant ratio of $5.6 \text{ to } 6.6 \times 10^4$ for PCB concentration in sediment to that in the associated water.^(a) Consequently, supernatant waters with 1 $\mu\text{g/l}$ (ppb) dissolved PCB or less would result from contact

(a) Halter, M. T., and H. E. Johnson, "A Model to Study the Release of PCB from Hydrosols and Subsequent Accumulation of Fish," Presented to ASTM Symposium on Aquatic Toxicity and Hazard Evaluation, Memphis, TN, October 25-26, 1976.

with sediments contaminated at 50 mg/l (ppm) PCB or less. Suspended solids contaminated with PCB would raise these levels. Recognition of the key role solids played in total PCB concentrations led to the investigation of use of flocculation agents and settling for supernatant treatment. In Hudson River studies, it was determined that 1 hr of settling in lagoons would effect 90% removal of PCB from effluent waters. The addition of a cationic polymer in that specific case increased removal. In three field trials, supernatant contained 50, 8 and 4.5 µg/l (ppb) PCB depending on the settling time provided. The cost effectiveness of this approach was deemed sufficiently high to warrant its recommendation for removal activities on the Hudson. While specific polymer requirements will vary with sediments, the success of work on the Hudson verifies the feasibility of the approach.

Removal of additional PCB, including soluble fractions, and that sorbed onto fine particulate matter can be achieved through filtration and, ultimately, sorption on activated carbon. In this approach, suspended matter is removed through physical entrapment in the filter bed while soluble levels are reduced through concentration on the carbon sorbent. This approach was applied on the Duwamish River with cartridge filtration. After filtration, supernatant concentrations were reduced from 8 to 10 mg/l (ppm) to 35 µg/l (ppb). Effluent from the carbon adsorption units contained less than 0.05 µg/l (ppb) PCB (the limited detection).

The successful demonstration of these approaches on the Duwamish makes them feasible candidates for use where very low supernatant PCB levels are required. Both approaches are considered as additional to sedimentation since the latter is required as a means of pretreatment prior to filtration or carbon adsorption. If powdered carbon is employed, the process can be accomplished in conjunction with sedimentation.

As noted earlier, exposure of PCB solutions to a combination of ultraviolet radiation and ozone has been found effective in reducing PCB concentrations. Studies at Westgate Research (San Diego, California) yielded effluents with less than 1 µg/l (ppb) PCB after contact for less than 1 hr. No large-scale facilities have been built to date, but extensive pilot work has been completed in San Diego. Designs for mobile facilities and cost estimation have also been conducted. UV/ozonolysis shows promise as a supernatant treatment alternative when high levels of PCB removal are required. However, the lack of full-scale experience on available equipment militates against its use at the present time.

Early work reported by Envirogenics, Inc., indicated the potential for reduction of chlorine functional groups on PCB using a copper-iron catalyst. If this could be accomplished, the resultant hydrocarbon skeleton would be susceptible to biochemical oxidation. Subsequent studies, however, have revealed that apparent PCB reduction was the result of retention on the catalytic column and not reduction. Very little chlorine release could be substantiated. Consequently, investigations related to Hudson River studies were suspended. With these questionable results and no large-scale experience, catalytic reduction cannot be considered a viable candidate for treatment of supernatant at this time.

Of the five approaches to supernatant treatment, three have been found to have sufficient promise to warrant detailed evaluation: 1) flocculation-sedimentation, 2) filtration, and 3) carbon adsorption. The first is the most simple and least expensive. The second may be necessary as an add on if lower PCB effluent levels are required. The third provides the greatest amount of removal. The three are not mutually exclusive, however. Sedimentation is necessary prior to filtration or granular carbon adsorption of dredged materials. Filtration is often necessary prior to carbon adsorption. Only in cases where sedimentation is highly effective can carbon adsorption be employed without prefiltration.

Disposal

The disposal of PCB and certain PCB-contaminated wastes, including dredge spoils, is controlled by regulations promulgated by the U.S. EPA under the Toxic Substances Control Act of 1976 (TSCA). Currently, these regulations apply only to those materials which contain 500 mg/kg (ppm) or more of PCB. However, proposed regulations would lower that limit to 50 mg/kg (ppm), and it is expected that within the next 8 to 9 months this level or a lower one will be adopted. Therefore, for purposes of this study, it is assumed that any spoils contaminated with 50 mg/kg (ppm) PCB will be required to be sent to a TSCA approved disposal facility. Because it is impossible for all practical purposes to determine which layers of spoils are contaminated at what level of PCB at a specific dredge location, spoils from all layers in those areas in which PCB was found at 50 mg/kg (ppm) at any depth shall be disposed of in accordance with TSCA regulations. Spoils from some portions of Waukegan Harbor where no layers exceed 50 mg/kg (ppm) could be segregated and routed separately to be sent to landfills with appropriate (if less stringent) protective safeguards.

Utilizing these criteria, it has been determined that if 100 mg/kg (ppm) is the threshold criteria, all 27,000 m³ (35,000 yd³) from the Harbor as well as the 2900 m³ (3800 yd³) from the North Ditch would require TSCA approved disposal. At a threshold of 10 mg/kg (ppm), 44,000 m³ (58,000 yd³) in addition to 4800 m³ (6300 yd³) from the North Ditch would require TSCA approved disposal and 33,000 m³ (44,000 yd³) would be exempted, while a threshold of 1 mg/kg (ppm), 48,000 m³ (64,000 yd³) in addition to 7400 m³ (9700 yd³) from the Ditch would require TSCA approved disposal and 72,000 m³ (109,000 yd³) would be exempted. The areas which would generate spoils requiring TSCA approved disposal are designated in Figure 26. Proposed regulations restrict disposal for these materials to two alternatives: 1) high temperature incineration, and 2) secured landfill.

Incineration--

As a part of the Hudson River Studies, researchers at General Electric Co., Inc. (Schenectady, New York) have studied the feasibility of incinerating PCB-contaminated spoils and delineated the necessary conditions for success. They determined that all PCB-contaminated sediments were destroyed in a gas-fired multiple hearth furnace when subjected to 1800 F (982 C) for a minimum of 0.5 sec in the afterburner.

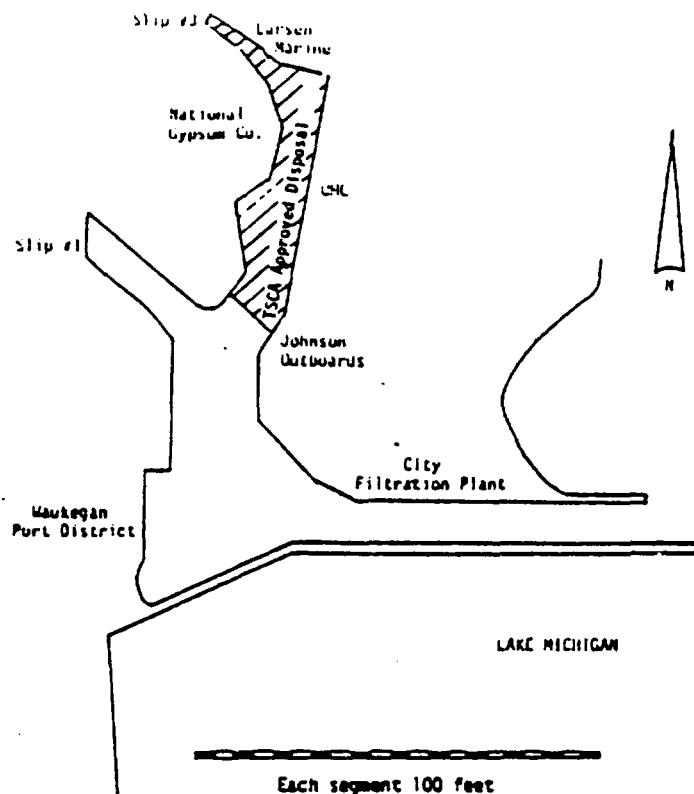


FIGURE 26. Areas of Dredging Requiring TSCA Approved Disposal

The associated costs were high. Capital and operating costs were minimized only when design capacity exceeded 86,000 m³/yr (114,000 yd³/yr - 10⁵ ton/yr). Present TSCA requirements require even greater temperature and dwell time requirements which would increase costs further. Costs will also be a function of water content. To date, no facilities in Region V have applied for or obtained a permit to incinerate PCB wastes. Consequently, this option would require construction of a new facility. Time and cost constraints would rule this alternative out for disposal of spoils from Waukegan.

Landfill--

Burial by approved chemical landfill disposal techniques has also been identified by the EPA as an acceptable means for disposing of PCB contaminated wastes and dredge spoils. These facilities are similar in concept to sanitary landfills for solid waste but offer protection from the generation and release of leachate. Leachate generation is of concern since monitoring of landfills in New York by the State Department of Environmental Conservation has revealed significant PCB migration from landfill sites into the surrounding environment as a result of uncontrolled leachate.

The desired level of leachate control is achieved through minimization of percolation, placement of impermeable liners beneath the cells, and/or the installation of a leachate collection system. Several landfill sites in Region V have previously handled PCB-contaminated wastes, and at least two

have applied for permits to continue to accept PCB under the TSCA disposal regulations. In addition, even if no TSCA-permitted disposal facility is available in Region V, the regulations provide that the Regional Administrator may, in the appropriate circumstances, allow disposal in other than a permitted landfill if adequate protection to health and the environment is provided at the alternative site. This option presents the possibility that a previously unpermitted landfill could be employed upon approval by the Regional Administration. Therefore, use of a chemical landfill must be evaluated in detail as an alternative for spoils disposal.

While spoils containing less than 50 mg/kg (ppm) (or the level set in final TSCA regulations) would be exempted from TSCA requirements, the imposition of requirements not made in the regulations for spoils with 50 mg/kg (ppm) may well be warranted in order to furnish adequate protection. Consequently, even though these materials may not be disposed of in the open waters of Lake Michigan, they could be buried in nearby protected landfills at substantially lower costs than those associated with chemical waste landfills. Based on this approach and the possibility of case-by-case approval by the Regional Administrator, the evaluation must extend to landfills not specifically permitted to accept PCB for disposal at present.

Spoils with less than 50 mg/kg (ppm) PCB would be exempted from TSCA regulations as currently proposed. These materials may not be disposed of in the open lake, but (as regards TSCA) could be buried in nearby landfills at substantially lower costs than those associated with secured landfills. Furthermore, should no permitted site be available for disposal of the spoils with \geq 50 mg/kg (ppm) PCB at a reasonable cost, the administrator may also grant special permission for disposal at an otherwise acceptable site. Hence, the evaluation must extend to nearby landfills not specifically associated with PCB disposal.

TECHNOLOGY SUMMARY

A number of alternatives have been suggested for reduction of contamination from persistent toxics in sediments. Results of a preliminary assessment of applicability of these alternatives to Waukegan are summarized in Table 4. As a result of this assessment, it has been determined that two options are sufficiently developed to warrant detailed evaluation: 1) in-place fixation, 2) physical removal (dredging/excavation). If the dredging alternative is selected, some degree of supernatant separation and treatment would be required as well as the ultimate disposal of spoils. Supernatant treatment can be achieved by flocculation-sedimentation, filtration, or carbon adsorption. The latter approach is employed when much lower effluent PCB concentrations are required. Disposal can be achieved through high temperature incineration, secured landfill, or fixation at the site of dewatering. The former is excessively costly for spoils. Specific clean-up procedures for detailed evaluation are selected for Waukegan Harbor and the North Ditch in the following sections.

TABLE 4. Summary Assessment of Alternatives

<u>Mode of Action</u>	<u>Comments</u>	<u>Status</u>
<u>In-Place Destruction</u>		
UV/ozone	Pilot stage, closed system only, unable to penetrate deep deposits	Eliminate
Biodegradation	Laboratory stage only, effective on PCB's with 4 chlorines only	Eliminate
Chemical Oxidation	Ineffective to date, conceptual	Eliminate
Radiation	Conceptual	Eliminate
<u>In-Place Fixation</u>		
Sorbents	Conceptual	Eliminate
In Place Stabilization	Successfully demonstrated in Japan, but no long-term effects data	<u>Evaluate</u>
In Place Stabilization		
Polymer Film Seal	Conceptual, limited effectiveness	Eliminate
<u>Removal and Disposal</u>		
<u>Removal</u>		
Retrievable Sorbents	Conceptual	Eliminate
Bioharvesting	Conceptual, limited effectiveness	Eliminate
Oil Soaked Mats	Conceptual	Eliminate
Solvent Extraction	Conceptual	<u>Eliminate</u>
Dredging/Excavation	Most fully developed alternatives	<u>Evaluate</u>
<u>Supernatant</u>		
Flocculation-Sedimentation	Effective to 1-10 ug/l (ppb)	<u>Evaluate</u>
Filtration	Yields lower effluent PCB concentrations	<u>Evaluate</u>
Carbon Adsorption	Yields much lower effluent PCB concentrations	<u>Evaluate</u>
UV/ozonolysis	Yields much lower effluent PCB concentrations	<u>Evaluate</u>
Catalytic Reduction	Ineffective	Eliminate
<u>Disposal</u>		
Incineration		<u>Evaluate</u>
Secured Landfill		<u>Evaluate</u>

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Waukegan Harbor

As a result of the preliminary assessment, two alternatives regarding contaminated sediments have been identified for evaluation. Selection of specific approaches must be made in light of the immediate environment within which clean-up is to be accomplished. In Waukegan Harbor, features which will play a role in the selection process include size (overall dimensions of the channel and slips), the desire to protect water quality, and costs.

Water depth in the Harbor limits physical removal options to dredging, since the costs of dewatering would be prohibitive for the work required. Exclusion of water to allow conventional excavation would be excessively expensive. Of the six types of dredges available in the Great Lakes, only three dredge types could be employed in the Harbor: hydraulic suction, Pneuma and Oozer. The clamshell, dragline and dipper must be accompanied by barges for receipt and transport of spoils. Because the width of the boat slips will not accommodate the dredge and barge alongside in an operating position, these approaches cannot be employed. Furthermore, these dredges would have difficulty operating around the seawalls. Therefore the evaluation is limited to hydraulic pipeline, Pneuma and Oozer dredges. Concern over suspension and loss of contaminated sediments will be greatest for the hydraulic pipeline dredge. Should these losses be deemed unacceptable, turbidity control devices, such as sediment curtains, may be required. Based on these considerations, three basic approaches must be evaluated for application to Waukegan Harbor:

1. Removal-Treatment-Burial

- a. Hydraulic Pipeline Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Secured Landfill
- b. Pneuma Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Secured Landfill
- c. Oozer Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Secured Landfill

2. In-Place Fixation

3. Removal-Fixation

- a. Hydraulic Pipeline Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Fixation
- b. Pneuma Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Fixation
- c. Oozer Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Fixation

North Ditch

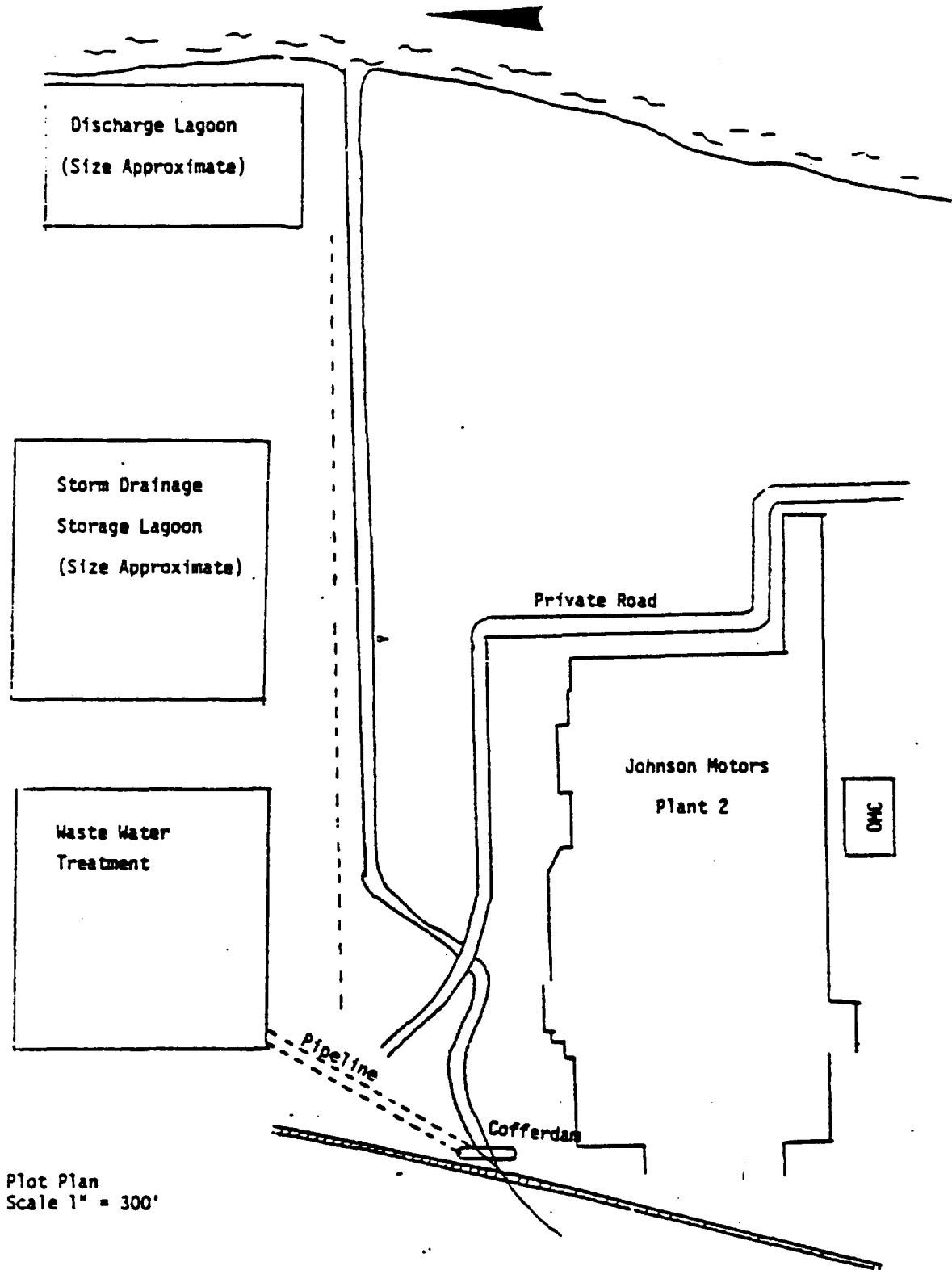
The extremely narrow width of the North Ditch and its minimal depth rule out use of any of conventional dredges. The shallow draft Mud Cat dredge would be applicable.

These dredges have been used at locations where they had to create their own channel as they entered mud flats, although the units work best in 53 cm (21 in.) of water. The Mud Cat could be used to advantage to dredge the contaminated materials from the North Ditch. Approaching from the Lake or discharge end of the Ditch the dredge could proceed inland cutting its way into the sediments and removing them without the need to restrict or redirect the effluent discharge water passing through the Ditch. Deadman anchors would be used to gain the forward dredge motion and the dredged material could be pumped directly through the dredge discharge line to the water/sediment treatment facility. Should the distance from the dredging site exceed the dredge's normal pumping distance [9.20 m (3000 ft)] a booster pump or pumps [one pump per 9.20 m (3000 ft)] could be used to extend the pumping distance. Greater labor requirements can be anticipated with respect to discharge pipe handling. This can be overcome by taking 61 to 92 m (200 to 300 ft) cuts and utilizing flexible lines between the dredge and the metal, overland discharge pipeline.

The topography of the North Ditch is such that a section of the north bank is supported by a steel bulkhead while the south bank has a natural slope. The bulkhead penetrates the sediment to a depth of 6.1 m (20 ft) and therefore should not be structurally threatened by cuts of up to 2.1 m (7 ft). This conclusion is based on discussions with the project engineer from Greely Hansen (contractor on the piling project) who noted that excavation in excess of 2.1 m (7 ft) was conducted on the north side of the sheet piling with no adverse effects. The available space between the roadway and the zone to be dredged is not sufficient to allow development of a natural and stable slope in the areas of deeper cut. Therefore, temporary support and backfill will be required or the road must be rerouted/modified to accommodate a 1:1 slope.

The presence of outfalls and storm flows as well as a high water table will restrict use of conventional excavation techniques. Consultation with excavating contractors has indicated that the use of highway type earth moving equipment to clean the sediments out of the North Ditch will not be a viable procedure. To gain entry of heavy excavation equipment into the Ditch the effluent flow would have to be diverted, requiring the installation of an on-land effluent pipeline since there is no available space to cut a temporary ditch. This could be accomplished with a pump and pipeline to the existing stormwater lagoons at the sewage treatment plant, as illustrated in Figure 27. In addition, the source of lake water intrusion into the Ditch for an estimated distance of 153 m (500 ft) would warrant a dam to be constructed to restrict entry of lake water into the Ditch. Following construction of a dam a pumping and dry maintenance program could be warranted. To successfully employ conventional earth moving equipment, a solid working surface must be assured.

NORTH SHORE SANITARY DISTRICT WASTEWATER TREATMENT PLANT



Plot Plan
Scale 1" = 300'

FIGURE 27. Possible Means of Flow Diversion for the North Ditch

A potential problem would arise from ditch flooding when a cut to a depth of 3.6 m (12 ft) (~ -5 ft present depth plus additional -7 ft cut) is made. The ENCOTEC report states that "the ground-water table below the ditch is at many times in direct contact with the ditch bottom." Based upon this information, any additional deepening could result in flooding, thereby excluding the use of conventional earth moving equipment and warranting the use of a dredge or roadside dragline or clamshell equipment.

The roadside operation would entail a cycle of trucks continuously ready to meet the production rate. At the storage site, the dump trucks would back up a specially prepared ramp to dump the load into the facility. Backfill could be loaded and brought to the Ditch on each return. If sufficiently dry, soils could be taken directly to a landfill. The roadside operation would greatly disturb the sediments within the trench, due to both the digging action and leakage of splashover from the drag bucket. In addition, leakage and/or splashover would occur from the truck bodies during the loaded trip to the treatment site.

If shoring is employed on the south bank, it could be moved with the excavation equipment and backfill put in place as the shoring is pulled. Ground-water control will require flood control with well points as employed during sewer excavation on the north side of the sheet piling. Pumped water would need to be routed to a treatment facility. Surface flow could be excluded by cofferdam and routed to the nearby wastewater treatment plant.

Based on the above considerations, three approaches to restoration of the North Ditch are identified for detailed evaluation:

1. Removal-Treatment-Burial

- a. Mud Cat Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Secured Landfill
- b. Roadside Excavation (with water intrusion control) - Secured Landfill

2. In-Place Fixation

3. Removal-Fixation

- a. Mud Cat Dredge - Sedimentation (with/without filtration and/or carbon adsorption) - Secured Landfill
- b. Roadside Excavation - Fixation

SECTION 5

ALTERNATIVES EVALUATION

Based on a finding of preliminary feasibility, candidate alternatives have been identified for detailed evaluation of clean-up actions in Waukegan Harbor and the North Ditch. Pertinent data and considerations are presented in this section to allow independent review of factors employed in selecting final recommendations.

WAUKEGAN HARBOR

Four basic approaches for Waukegan Harbor have been identified as a result of the preliminary assessment. These correspond to use of in-place fixation or one of three dredging devices: a hydraulic suction pipeline dredge, the Pneuma dredge, or the Oozer dredge. If dredging is employed, sediment dewatering and supernatant treatment will be required as well as ultimate disposal of spoils. Dewatering can be accomplished through polymer-assisted settling in sedimentation lagoons. Greater degrees of PCB effluent concentration reduction can be achieved through filtration, filtration-carbon adsorption, or addition of powdered activated carbon. Three potential disposal sites have been identified for secured landfill of sediments.

Hydraulic Suction Pipeline Dredge

As noted previously, a hydraulic suction pipeline dredge operates through a vacuum cleaner-like action which draws dislodged sediments into a pipeline and pumps them to a disposal area.

A hydraulic dredge of nominal size (as described below) would be needed to raise the PCB-contaminated sediments from the Waukegan Harbor bottom. Such a dredge should meet the inner-harbor waterdepth demands as charted on U.S. DOC/NOAA/NOS Navigation Chart 14904 [maximum sounded depth 6.3 m (21 ft)]. A 25-cm (10-in.) or 31-cm (12-in.) diameter pipeline dredge could reasonably undertake the proposed dredging operation. Such a unit would have overall dimensions of approximately:

Length	27.5 m	(90 ft)
Width (beam)	5.1 m	(17 ft)
Height	9.9 m	(33 ft)
Draft	109 cm	(43 in.)
Freeboard	43 cm	(17 in.)
Production Rate	45-225 m ³ /hr	(60-300 yd ³ /hr)
Dredging Depth	7.6 m	(25 ft)
Maximum Dredge Cut	46 cm	(18 in.)

The dredge described would meet the contaminated sediment dredging-depth demands, with the exception of one area in the Harbor. This location would demand a maximum dredging depth of 7.7 m (25.5 ft) to recover contaminated sediments down to the PCB level of 1.0 mg/kg (ppm). To fully dredge this area, the services of a dredge capable of accepting an extended dredging ladder might have to be located. These ladders are normally available within the Great Lakes area.

This type of dredge could, through its discharge line, pump the dredged material directly to a selected sediment/water-treatment site, thereby eliminating the need for barge or scow transportation. Depending on the overall distance from the dredge to the treatment site, a booster pump or pumps may be needed to gain complete transportation from the dredge to treatment site.

To improve the capture of contaminated sediments and suppress suspension, it is suggested that the 10-in. suction pipeline be equipped with a specially fabricated suction head. The head should increase the cross-sectional area of the suction pipeline by a factor of at least three. A bell-shaped suction head having a mouth opening of 25 cm (10 in.) in the vertical plane and at least 91/cm (36 in.) in the horizontal plane is advisable to provide a wider dredging sweep and to permit the "vacuum" to operate on a wider face of material. In this manner, production is increased during each swing since more material is picked up by the bell suction over the plain "nose" of a 25-cm (10-in.) suction pipe. Additionally, the percentage of solids to liquids should be materially increased (Figure 28).

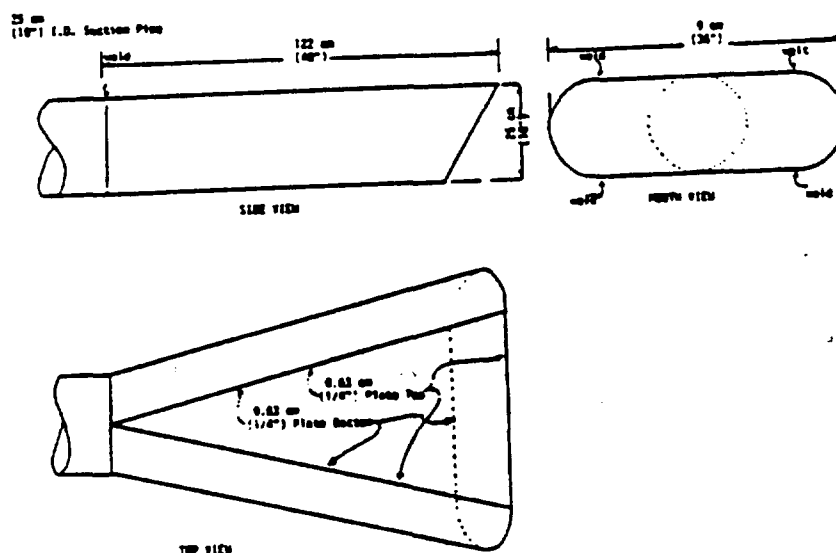


FIGURE 28. Basic Design of Proposed Hydraulic Suction Head

A conventional pipeline dredge would have problems working within the confines of the Larsen Marine boat basin; it could not use its anchoring system for forward movement, but could revert to the use of land-based anchoring systems. Maneuverability may also be difficult around the pilings in the slip area. As a consequence, other options may be desirable for the confines of the Larsen Marine boat basin.

As noted previously, hydraulic suction dredges will lead to suspension of contaminated sediments in the water column and possible dissolution of contaminants. Previous studies of dredging operations allows for some quantitative discussion of the magnitude of these possibilities. Much of the turbidity associated with hydraulic dredges has been attributed to cutterheads employed with the units. The sediments of interest in Waukegan Harbor are sufficiently unconsolidated to accommodate direct suction without a cutterhead. This method, in conjunction with the recommended suction head, will minimize sediment losses. Suspended sediment observations reported for cutterhead-suction dredge combinations are summarized in Table 5.

TABLE 5. Suspended Sediments Field Observations Raised by Cutterhead-Suction Dredges

Size of Head cm (in.)	Background Concentrations, mg/l	Distance from Head (m)	Suspended Solids (mg/l)
61 (24)	25-30	30	336 (1.5 m from bottom)
		300	125 (1.5 m from bottom)
68 (27)	39-209	2	39-580 (73 m to side)
61 (24)	1-18		2-31,000 (15-31 cm deep)
		2	1-16,000 (15-31 cm deep)
		3	1-4,000 (15-31 cm deep)
		60	1-17 (near surface)
			5-205 (near bottom)

These limited data indicate that suspended sediment problems will be localized around the cutterhead. Relative turbidity levels increase with depth of cut swing rate and cutter rotation. Since no cutterhead is required in Waukegan Harbor, data in Table 5 represent an extreme which would not be approached. In studies on the Hudson River with a 37-cm (15-in.) hydraulic dredge, river quality was affected by a net increase of 1 mg/l (ppm) suspended solids, 0.018 µg/l (ppb) PCB (0.096 lb/day) across the cross section of the River. These resulted from values at the dredge head of 2.1 µg/l (ppm) PCB and 120 mg/l (ppm) suspended solids. As a result of their studies, staff from the New York Department of Environmental Conservation estimated that 2% of all dredged materials would be suspended and that 20% of these associated PCB would desorb or remain suspended. Hence, losses would approximate 0.4% of the PCB bed load. Much of their losses can be attributed to use of the cutterhead. The unit for Waukegan Harbor would not incorporate a cutterhead. Results of work at the U.S. Corps of Engineers Waterways Experimental Station suggest that losses would be significantly less.

With respect to desorption of PCB during dredging, limited laboratory studies for the U.S. Corps of Engineers Waterways Experiment Station resulted in no measurable losses associated with sediment to water ratios of 1:10 or less. Since this is the volume ratio to be employed with hydraulic dredging of Waukegan Harbor, no impacts from desorption are anticipated.

Finally, it should be noted that localized increases in contaminated suspended sediments should not in themselves constitute an acute impact. It has been shown that PCB is toxic to aquatic life with acute exposure to these low concentrations. Rather, the major impacts caused by PCB appear to result from chronic exposure and bioconcentration in the food chain. Therefore, sediment suspension during dredging is of concern largely from the standpoint of accelerated transport into Lake Michigan and degree to which these materials represent continuing residual contamination, i.e., removal effectiveness.

A 25-cm (10-in.) hydraulic suction pipeline dredge is capable of moving up to 225 m³/hr (300 yd³/hr) of sediments, which amounts to 5400 m³ (7200 yd³) per 24 hr working day. For large jobs, the unit cost approximates \$1.50/yd³ of sediment. For small jobs, mobilization and demobilization costs can raise unit costs to as high as \$6.70/m³ (\$5.00/yd³). In Waukegan Harbor, costs are likely to average \$4.00/m³ (\$3.00/yd³). Total costs for use of a 25-cm (10-in.) hydraulic suction pipeline dredge in Waukegan Harbor are enumerated in Table 6.

TABLE 6. Total Costs for Use of Hydraulic Dredge in Waukegan Harbor

<u>Dredge Threshold, mg/kg PCB</u>	<u>Time Required, days</u>	<u>Unit Cost/m³, yd³</u>	<u>Total Cost</u>
100	6	\$5.30 (\$4.00)	\$140,000
10	16	\$4.00 (\$3.00)	\$306,000
1	27	\$4.00 (\$3.00)	\$519,000

Oozer Dredge

The Oozer dredge operates much the same as the Pneuma dredge except that it employs vacuum to augment hydrostatic pressure for filling the chamber. Hence, the dredge chamber is lowered to the sediment and evacuated by means of hoses to the surface. Once evacuated, the chamber parts are opened to the sediments which are subsequently drawn into the chamber bath by force of the vacuum and by the pressure differential created by the hydrostatic head of the water column. Sediments are then pumped from the chamber to a disposal site through injection of compressed air. Field data indicate that spoils produced may vary between 50 and 75% solids. A conservative value of 50% solids on a volume basis is employed here for the purposes of cost estimation.

The manufacturer has reported that limited studies with the Oozer indicate minimal suspension of sediments during the dredge operation. Consequently, this technology is touted to be associated with little or no turbidity and subsequently fewer related environmental impacts than a hydraulic dredge. The question of operation as a foreign dredge in U.S. waters is of more importance since this could rule out its use.

There is a readily transportable dredge available in Japan having the following dimensions:

Overall length	20 m (66 ft)
Beam	8 m (26 ft)
Depth	1.8 m (5.9 ft)
Dredging depth	6 m (19.6 ft)

However, this dredge, as such, would not be shipped to the U.S. Federal law prohibits the use of foreign dredges in the U.S. If Federally approved, the pumping system could be delivered for attachment onto a conventional pipeline dredge as described previously or onto a barge modified to accommodate the pumping system. This scheme would also expedite shipping.

As noted previously, the dredging capacity of the unit when pumping over a distance of 100 m (2300 ft) is in the range of 2400 m³/hr (3144 yd³/day). Personnel of the Corps of Engineers, Norfolk, Virginia, who have viewed this pump in operation, estimate that the operating cost is about \$4.75/m³ (\$3.54/yd³) whereas the Project Director of the Machinery Division of Marubeni American Corporation as the Oozer dredge representative in New York states that \$5.3 to 6.7/m³ (\$4 to \$5 yd³) would be a more practical costing. On this basis, completion of the Waukegan Harbor dredging project with an Oozer dredging system operating at \$6/m³ (\$4.50 yd³) would generate the costs provided in Table 7.

TABLE 7. Cost of Use of Oozer Dredge in Waukegan Harbor

Dredge Threshold, mg/kg PCB	Volume of Sediments, m ³ (yd ³)	Time Required, Days	Mobilization Demolization Cost	Operational Cost	Total Cost
100	27,000 (35,000)	13	\$50,000	\$158,000	\$208,000
10	78,000 (102,000)	37	\$50,000	\$459,000	\$509,000
1	132,000 (173,000)	63	\$50,000	\$779,000	\$829,000

The costs in Table 7 do not reflect transportation expenses, which would include \$40,000 for transport from Japan to the West Coast, additional transportation costs for movement to the Great Lakes, and the expense of fitting the pumping system to a conventional hydraulic dredge.^(a)

(a) It should be noted that representatives of the Japanese parent firm are anxious to have a demonstration conducted in the U.S. and have suggested the possibility of bearing some of these costs. However, at this time the size of these costs and nature of any cost-sharing cannot be quantified. Since they may well be small compared to total costs, this uncertainty does not greatly affect the present evaluation.

Pneuma Dredge

The Pneuma dredge operates in a manner quite similar to that of the Oozer in that a dredging chamber is used; however, no vacuum is employed. Instead, the emptied chamber is opened to the sediments which are then carried into the chamber as a result of water movement created by the hydrostatic pressure of the water column. Sediments are then forced from the chamber with compressed air and pumped to the disposal site. As with the Oozer, a high solids content (50 to 75%) is maintained in the product slurry. A conservative value of 50% on a volume basis was employed for estimation purposes. Similar to the Oozer, the Pneuma dredge is purported to reduce sediment suspension. Consequently, related environmental impacts are less than those associated with a hydraulic system.

The Pneuma dredge unit employed on the Duwamish River may be available from the Chicago-based American supplier, Pneuma North American, Inc. Detailed data on dimensions, costs and other considerations were made available by the firm for estimation purposes. Estimates are based on available data from two previous projects where production rate and product solids content were monitored. There is a rental fee of \$500/day (operation for 8 of 10 working hr/day) and \$450/day operation costs for a three man crew. Additional expenses for the technician raises costs to \$1000/day. There is an additional cost for workboat rental and miscellaneous piping amounting to \$750/day. Unit costs are estimated at \$0.53 to \$0.80/m³ (\$0.40 to 0.60/yd³) depending upon the size of the job and its location. Mobilization costs are estimated at \$15,000. Cost estimates for dredging Waukegan Harbor with a Pneuma dredge are provided in Table 8.

TABLE 8. Cost of Dredging Waukegan Harbor with a Pneuma System

Dredge Threshold, mg/kg PCB	Volume of Sediments m ³ (yd ³)	Time Required, days	Mobilization Cost	Operational Cost	Total Cost
100	27,000 (35,000)	11	\$15,000	\$18,700	\$34,000
10	78,000 (102,000)	32	\$15,000	\$54,400	\$70,000
1	132,000 (173,000)	55	\$15,000	\$93,500	\$109,000

The mobilization costs in Table 8 are low based on the assumption that transportation is likely to be minimal, since Pneuma North America, Inc., is located in Chicago. The unit itself, however, must be mounted on a workboat. When utilized on the Duwamish River, a Federal vessel was employed. It must be noted that the costs estimated here [\$24,000 for 27,000 m³ (35,000 yd³)] are based on operation at capacity and not the limited amount of historical data. On the Duwamish, total dredging costs were \$109,000 for 11,000 to 15,000 m³ (15,000 to 20,000 yd³). That is a unit cost roughly eight times higher than projected. Some of the differential lies in the amount of solids actually pumped (30%) as opposed to 50% and the need to continually shut down to clear dredge heads of trash and debris. Recognizing this and the lack of confirmatory data on operational costs, unit costs for the Pneuma must be considered an estimate at this time with the potential for being significantly higher.

Recently, tests of the Pneuma dredge, sponsored by the U.S. Army Corps of Engineers on the Cape Fear River, were conducted. A detailed report of observations is available in Appendix A. Basically, the dredge was found to have the same blocking or choking problems noted during operation on the Duwamish River. The actual rate of dredging during this trial was recorded at 240 m³ (315 yd³) in a 3-hr period or 80 m³/hr (105 yd³/hr). Much of this is attributable to the discovery that the dredge head was not resting on the bottom during the first 2 hr, but was merely pumping water and sediments as they sloughed into the dredged depression on the bottom. The captain of the hopper dredge receiving the spoils estimated a total solids dredging rate of 8 m³/hr (11 yd³/hr). This is a factor of 40 less than that reported. Even if all the dredging occurred in the final hour, it would equate to a rate one-thirteenth of that claimed. In addition, operation was reported to be accompanied by a significant level of turbidity.

Based on the above data and lack of any substantiation for the reported dredging rate of the Pneuma, it is believed that production capabilities have been overstated and should be estimated at a rate of 27 m³/hr (36 yd³/hr). It is reported that Pneuma North America is evaluating redesign, and may improve this figure in the future, but this has not yet been accomplished. As a result of the above considerations, estimates for dredging Waukegan Harbor (Table 8) should be revised as presented in Table 9.

TABLE 9. Revised Cost of Dredging Waukegan Harbor with a Pneuma System

Dredge Threshold, mg/kg PCB	Volume of Sediments m ³ (yd ³)	Time Required, days	Mobilization Cost	Operational Cost	Total Cost
100	27,000 (35,000)	122	\$15,000	\$ 207,000	\$ 222,000
10	78,000 (102,000)	354	\$15,000	\$ 602,000	\$ 617,000
1	132,000 (173,000)	600	\$15,000	\$1,020,000	\$1,035,000

Sedimentation

Given the availability of required space, the simplest and most cost effective means of supernatant treatment is sedimentation. It has been found that the bulk of all PCB contamination in dredge spoils is associated with the solids. Hence, PCB on the larger solids can be removed from supernatant by allowing the solids to fall to the bottom of the settlement basin. Additional PCB can be removed if finer particles are agglomerated and allowed to settle. This can be facilitated through application of coagulants.

Sedimentation proved highly effective in studies on the Hudson River. As noted earlier, 1 hr of settling provided 90% removal of PCB from supernatant, resulting in residual levels below 1.5 µg/l (ppb). The use of cationic polymers increased removal efficiencies. From these studies, staff determined that for a 38-cm (15-in.) pump, treatment lagoons should be at

least 310 m by 155 m (1000 ft by 500 ft) and enclosure dikes 3 to 4.5 m (10 to 15 ft) high. Capacity should be sufficient for a minimum retention time of 1 hr. Three cationic polymers were shown to be effective on the Hudson. However, screening studies will be required to select an optimal polymer for the specific sediments found in Waukegan Harbor.

In the Hudson studies, the addition port was some 4.5 m (15 ft) downline of the pump and polymer was added as a one-tenth solution with tap water. Good results were also obtained when the polymer was fed by gravity into an intermediate weir box through a diffuser pipe (a hose with a feeder hole) using dredge water to achieve the 10 to 1 dilution. When a 38 cm (15-in.) diameter pump was employed during a 16-hr day, \$500/day of flocculants were added. It was also noted that highly contaminated scums were found at some of the retention barriers.

The Waukegan Harbor and North Ditch sites are amenable to construction and use of a sedimentation lagoon for supernatant treatment. A large, open, fenced lot owned by Outboard Marine Corporation lies due east of slip No. 3 and less than 0.81 km (0.5 mi) from the mouth of the North Ditch.. The land is low and relatively flat. It could accommodate a diked area of up to 360 m by 240 m (1200 ft by 800 ft) using dikes above grade. Excavation would not be advisable because of the proximity of Lake Michigan and the shallow water table (see Figure 29). The dimensions of the required lagoon will vary with the dredging option selected. It will be based on a minimum overflow rate of $33 \text{ m}^3/\text{day}/\text{m}^2$ (800 gpd/ft²), and an average supernatant height above the sediment bed of 1 m (3 ft). This design will protect against sediment suspension from wave action. An additional 1 ft of freeboard will also be provided to ensure against overflow from wave action. Diking will be based on a maximum 3 m (10 ft) height and a 2 to 1 slope using compacted fill material. Based on these criteria, the dimensions of the required lagoons for each dredging option are given in Table 10.

Since there may be distinct cost advantages in segregating spoils contaminated at $\geq 50 \text{ mg/kg}$ (ppm) PCB from those with $< 50 \text{ mg/kg}$ (ppm), the lagoon should be divided by a dike dissecting the total area into two lagoons of equal dimensions. The northern half would receive highly contaminated spoils from the vicinity of Slips 1 and 3, while the southern half would receive spoils from the Waukegan Harbor channel area (Figure 26). Since only one of the two halves would be receiving spoils at any specific time, the overflow would be routed to the second half, which would act as a second settling unit for further clarification. At the capacity of the dredging options being considered [$5400 \text{ m}^3/\text{day}$ ($7200 \text{ yd}^3/\text{day}$) for the pipeline dredge and $2700 \text{ m}^3/\text{day}$ ($3600 \text{ yd}^3/\text{day}$) for the Oozer and Pneuma dredges] and the reported proportions of transport water to spoils, the lagoon would always provide detention in excess of the minimum 1 hr and overflow rates less than $33 \text{ m}^3/\text{day}/\text{m}^2$ (800 gpd/ft²). This operational level is more than adequate for good settling. Overflow weir heights of 2.7 m (9 ft) provide the desired 0.3 m (1 ft) of freeboard to prevent splash over.

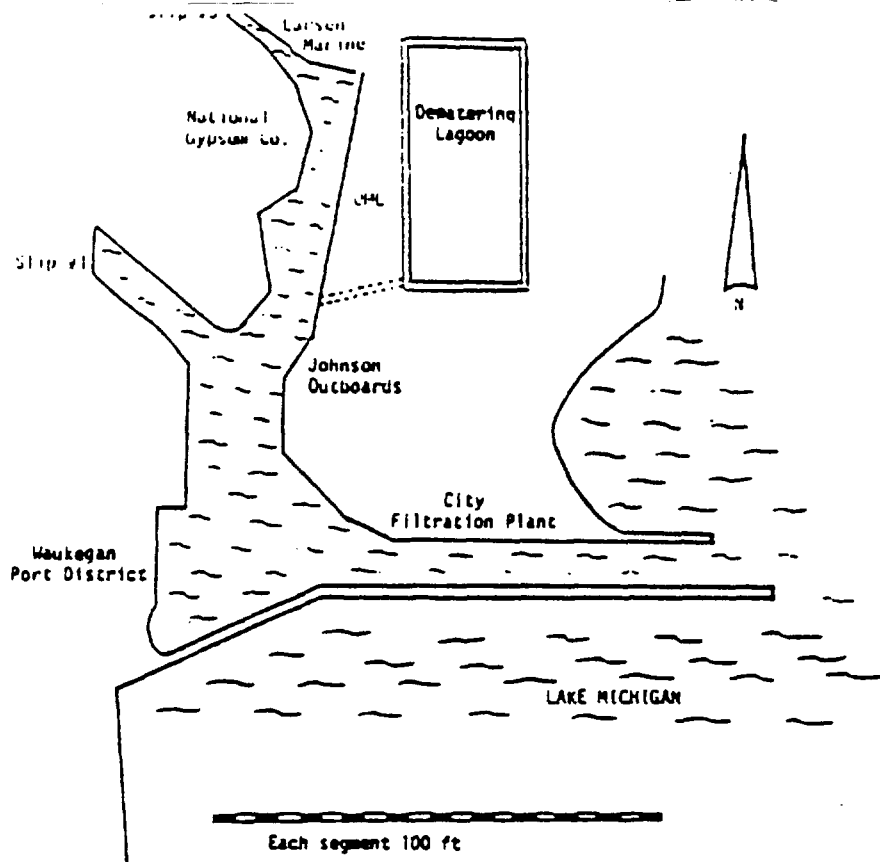


FIGURE 29. Site of Proposed Dewatering Lagoons

TABLE 10. Dimensions of Required Settling Lagoons for Spoils Dewatering

Dredge	mg/kg ppm PCB Threshold	Sediment Volume m ³ (yd ³)	Supernatant Flowrate m ³ /day (gpd)	Area Dimensions m x m (ft x ft)	Height m (ft)	Overflow Rate m ³ /d/m ² (gpd/ft ²)	Final Day Detention Time (hrs)
Hydraulic	100	27,000 (35,000)	57,000 (15,000,000)	120 x 120 (900 x 500)	3 (10)	378 (94)	6
	10	78,000 (102,000)	57,000 (15,000,000)	270 x 150 (900 x 500)	3 (10)	132 (33)	15
	1	132,000 (173,000)	57,000 (15,000,000)	300 x 240 (1000 x 800)	3 (10)	78 (19)	25
Pneum. or Oozer	100	27,000 (35,000)	2,900 (750,000)	120 x 120 (400 x 400)	3 (10)	20 (5)	13
	10	78,000 (102,000)	2,900 (750,000)	270 x 150 (900 x 500)	3 (10)	8 (2)	46
	1	132,000 (173,000)	2,800 (750,000)	300 x 240 (1000 x 800)	3 (10)	4 (1)	615

The dikes and floor of the lagoon would be sealed through application of a layer of bentonite clay or its equivalent, preventing contamination of ground water or damage to the dike itself. Recommended application rates are 3.5 to 7 kg/m^3 (10 to 20 lb/yd) mixed to a depth of 9 cm (6 in.) in the soil.

The investigators in the Hudson River studies suggest use of a labyrinth to promote further settling prior to discharge. This constitutes added costs which should not be necessary with the lengthy detention times proposed in this case. The overflow gate between the two halves of the lagoon should be set at the western end of the divided dike to provide a similar enhancement of settling. Final discharge would be achieved by means of overflow weirs set in the top of the dike at the northeast and southeast corners of the lagoon (Figure 30). Supernatant would be piped 180 m (600 ft) back into the Harbor for discharge.

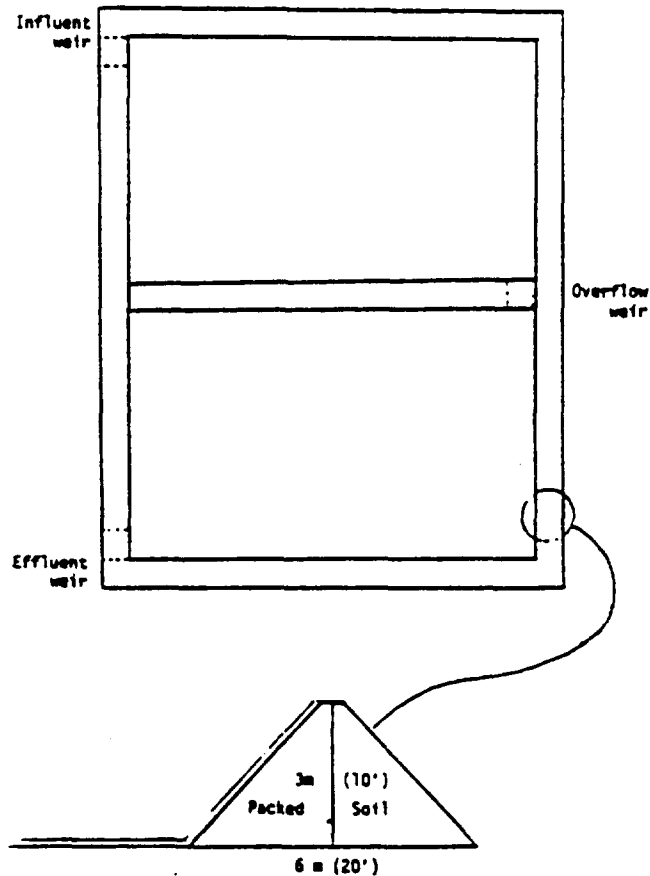


FIGURE 30. Design of the Spoil Dewatering Lagoon

Impacts of the dewatering will largely result from construction of the required lagoon and discharge of treated supernatant. Both activities would require permits from local and state authorities; the construction itself would generate noise and dust conditions; and the site is near a public beach and the frequently used Larsen Marine Boat Basin. Hence, operations during the spring and summer (through October) would be most likely to affect the public. Operation during winter months would ensure much less contact. The operation (time of day, points of access and egress, coverage of trucks, etc.) can be designed to minimize this contact.

Due to the long detention times proposed, discharges should contain less than 10 ug/l (ppb) PCB. If that level is sustained, total PCB releases would amount to 13.6 kg (~30 lb) as delineated in Table 11. This is less than 0.006% of the total estimated quantity of PCB in the Waukegan Area.

TABLE 11. PCB Content of Proposed Supernatant Discharges from Sedimentation Treatment at 10 ppb

<u>Alternative</u>	<u>Total Volume of Supernatant Discharged, m³ (gal)</u>	<u>Total Quantity of PCB Discharged, kg (lb)</u>
Hydraulic Pipeline Dredge		
Dredge Threshold 100 ppm	290,000 (76,000,000)	2.8 (6.1)
Dredge Threshold 10 ppm	83,000 (220,000,000)	8.2 (18)
Dredge Threshold 1 ppm	1,400,000 (375,000,000)	13.6 (30)
Oozer or Pneuma Dredge		
Dredge Threshold 100 ppm	34,000 (9,000,000)	0.33 (0.72)
Dredge Threshold 10 ppm	85,000 (22,500,000)	0.82 (1.8)
Dredge Threshold 1 ppm	160,000 (41,300,000)	1.5 (3.3)

Costs for sedimentation treatment of supernatant have been broken into five elements: construction of the lagoon, sealing of the lagoon, flocculants, discharge piping, and operational labor. Total costs will differ depending on threshold of dredging selected [1, 10 or 100 mg/kg (ppm) PCB], i.e., sediments and the need for segregation. Unit costs for the purposes of estimation of lagoon construction were \$8/m³ (\$6/yd³) for diking 16 m³/linear meter (3.7 yd³/linear foot). Cost of sealing with bentonite was determined from the EPA formulate $m = [7121.9(V) + 1415.6](a)$

where

L = cost in dollars

m = factor dependent on material (0.86 for bentonite in 1977, estimated at 7% higher or 0.92 for 1978) and

V = volume of the Tagoon in millions of gallons

(a) Pound, C. E., R. W. Crites, and D. A. Griffen, 1975. Costs of Wastewater Treatment by Land Application, U.S. Environmental Protection Agency Technical Report 430/9-75-003.

Hudson River studies determined a cost of \$500/day for flocculants when a 38-cm (15-in.) pipeline dredge was employed for 16 hr. This translates to \$0.60/m³ (\$0.45/yd³) of material pumped for flocculant. They also determined that more than 1 hr/day of labor was required to clear and service the hoses and pumps. Another hour would be added for adjustment and inspection of weirs. This was estimated at \$10/hr. A discharge pipe, 180 m (600 ft) long would be required at \$23/linear meter (\$7/linear foot) for installation, use, and removal (\$5/linear foot for lower flowrate approaches). These cost factors yield total sedimentation elutriate treatment costs for each as outlined in Table 12. Since the lagoon is to be above grade, removal costs will be those associated with the berm removal approach.

TABLE 12. Cost of Supernatant Treatment by Sedimentation

Dredge Option	Dimensions m x m (ft x ft)	Cost to Construct Lagoon	Cost to Seal Lagoon	Cost of Flocculant	Operation Labor Cost	Cost of Discharge Pipe	Total Cost
WITH SEGREGATION OF SPOILS:							
10" Hydraulic pipeline							
Dredge Threshold 10 ppm	270 x 150 (900 x 500)	\$72,600	\$217,300	\$4691	\$ 320	\$4200	\$319,000
Dredge Threshold 1 ppm	300 x 240 (1000 x 800)	\$96,800	\$421,000	\$7960	\$ 540	\$4200	\$531,000
Oyster or Pneum. Dredge							
Dredge Threshold 10 ppm	270 x 150 (900 x 500)	\$72,000	\$237,000	\$ 938	\$ 700	\$3000	\$314,000
Dredge Threshold 1 ppm	300 x 240 (1000 x 800)	\$96,000	\$421,000	\$1590	\$1200	\$3000	\$524,000
WITHOUT SEGREGATION OF SPOILS:							
10" Hydraulic pipeline							
Dredge Threshold 100 ppm	120 x 120 (400 x 400)	\$15,200	\$ 95,200	\$1610	\$ 120	\$4200	\$126,000
Dredge Threshold 10 ppm	270 x 150 (900 x 500)	\$41,600	\$237,000	\$4690	\$ 320	\$4200	\$308,000
Dredge Threshold 1 ppm	300 x 240 (1000 x 800)	\$79,200	\$421,000	\$7960	\$ 540	\$4200	\$513,000
Oyster or Pneum. Dredge							
Dredge Threshold 100 ppm	270 x 120 (900 x 400)	\$35,200	\$ 95,200	\$ 332	\$ 240	\$3000	\$124,000
Dredge Threshold 10 ppm	270 x 150 (900 x 500)	\$41,600	\$237,000	\$ 938	\$ 700	\$3000	\$303,000
Dredge Threshold 1 ppm	300 x 240 (1000 x 800)	\$79,200	\$ 71,000	\$1590	\$1200	\$3000	\$304,000

Filtration With or Without Carbon Adsorption

Sedimentation treatment of supernatant is capable of producing effluents with PCB residuals in the 1 to 10 parts per billion (µg/l) range. If this is deemed inadequate and greater reduction levels are required, filtration and/or possibly carbon adsorption would be necessary. Carbon adsorption cannot be applied alone, however, but must be preceded by sedimentation and filtration to remove the bulk of the all solids which would blind the carbon column. Filtration is aimed at physical entrapment of contaminated solids that were too small for removal by sedimentation. The adsorption phenomenon is believed to result from interactions between the sorbate and the surface of the sorbent. In the case of carbon, each particle has a myriad of channels and chambers that create an extensive surface area. Many organic materials, and especially hydrophobic organic materials, are held to this area by surface changes. Hence, when contaminated water is filtered through a bed of activated carbon, the trace organic pollutants sorb onto the carbon and are removed.

Laboratory and field studies with PCB have shown carbon to be highly effective at removing the soluble fraction. Field work on the Duwamish River resulted in virtually nondetectable levels of PCB in carbon column effluents ($<0.005 \mu\text{g}/\text{l}$).

Application of carbon to supernatant from Waukegan Harbor dredge spoils could be achieved in several ways: 1) a temporary treatment facility could be conducted or a mobile treatment unit could be brought to the dewatering site and 2) powdered activated carbon could be added to the sedimentation lagoon along with coagulant. The first options would require a unit capable first of sand filtration to protect the carbon columns and then contact with a column of granular activated carbon. Since mobile facilities are available from the Calgon Corporation, mobile units would be the preferred recourse for Waukegan; these units would eliminate the need to construct and remove a temporary facility. However, these units have a design capacity and maximum output of no more than 1900 to $2300 \text{ m}^3/\text{day}$ ($500,000$ to $600,000 \text{ gpd}$). Hence, 30 units would be required to treat the estimated $57,000 \text{ m}^3/\text{day}$ ($15,000,000 \text{ gpd}$) of elutriate from the 25 cm (10-in.) hydraulic dredge. Two units could handle the $2800 \text{ m}^3/\text{day}$ ($750,000 \text{ gpd}$) from operation of a Pneuma or Oozer dredge.

The Calgon Corporation has also designed a temporary carbon treatment facility which could be constructed for short-term use on contaminated supernatant. The flow scheme and dimensions for a $190,000 \text{ m}^3/\text{day}$ (50 MGD) unit are illustrated in Figure 31. Calgon estimates of capital costs for a

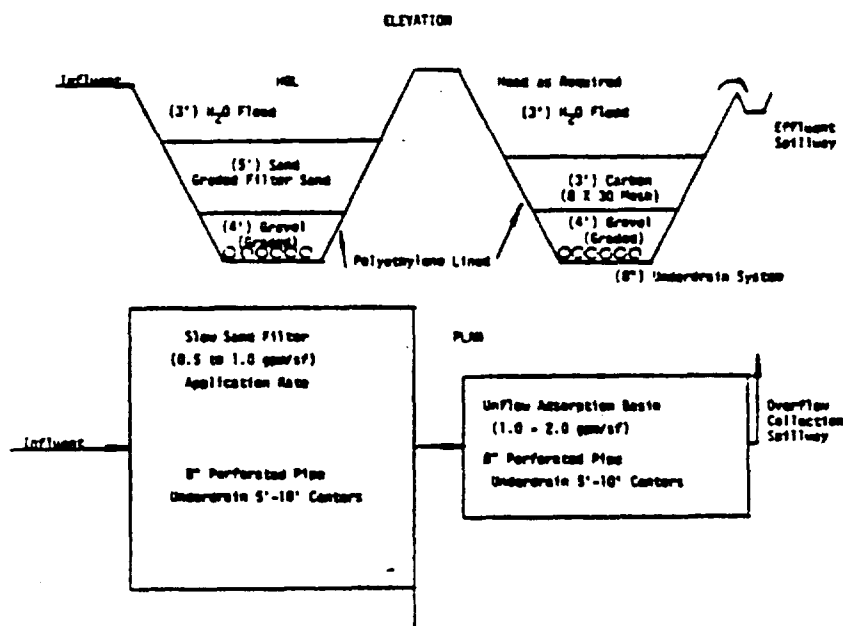


FIGURE 31. Temporary Treatment System, Dredge Water
(Courtesy of Calgon Corporation)

190,000 m³/day (50 MGD) module are presented in Table 13 along with estimates for scaled-down versions of each required at Waukegan. Such a scheme can also be employed for filtration only. Estimates for filtration alone are also given in Table 13. The scaled-down estimates were derived from those by Calgon using the 0.6 exponential factor. Spent carbon would be added to the dry spoils for disposal. Operating costs would be limited to labor at roughly \$240/day (24 hr at \$10/hr), which would augment total costs as detailed in Table 14.

If the Pneuma or Oozer dredges are employed, total supernatant flow will drop to 2900 m³/day (750,000 gpd). This reduced flow could be treated with a mobile carbon adsorption system such as that available from the Calgon Corporation. These units are transportable facilities containing two 3 m (10 ft) diameter adsorbers charged with 9100 kg (20,000 lb) of granular activated carbon apiece. Each facility can treat up to 1900 m³/day (500,000 gpd). Two units would readily handle the anticipated 2900 m³/day (750,000 gpd) of supernatant. The units could be made available in Waukegan for a \$50,000 onetime mobilization-demobilization charge (includes first month of operation), and a \$5,000 charge/month after the first month. Since Calgon's regeneration furnace has not been approved for disposal of PCB, carbon would be added to the spoils and buried rather than recovered. This would add an additional \$12,000 cost [based on \$0.66/kg (\$0.30/lb) of carbon and 18,000 kg (40,000 lb) total inventory]. Calgon assists in mobilization start-up, demobilization and technical troubleshooting. They recommend staffing with a single man for a single shift at a nominal cost of \$80/day (\$10/hr). Based on these values, anticipated costs can be estimated as presented in Table 15.

If powdered carbon were employed, it would be slurried and added to the spoils discharge line upstream of the flocculant addition point. This approach minimized capital expenditures by utilizing the sedimentation facilities for contact and settling. Costs would be associated with the carbon itself, the carbon addition equipment, and labor. A nominal carbon dose of 200 mg/l is employed here for estimation purposes. (Laboratory studies would be required to refine that value.) Unit costs would include \$0.66/kg (\$0.30/lb) of powdered carbon, \$20,000 for automated feed equipment for high flowrate systems, \$1000 for manual carbon addition equipment for low flow systems, and \$240/day operating labor. Total costs for powdered carbon use are presented in Table 16. A review of the data shows that the use of powdered carbon will be more cost effective than the use of granular carbon and/or filtration. While filtration is not included in the powdered carbon option, it should be noted that carbon addition has been found to enhance settleability of suspended solids and hence produces effluents, intermediate between settling and filtration.

Carbon adsorption treatment of elutriates will not eliminate the necessity of obtaining a temporary discharge permit. It will reduce political impacts from release of PCB, however. The only adverse environmental effects which would be incurred are those associated with losses of carbon dust to the atmosphere and the increase in total solids

TABLE 13. Capital Cost Estimates for Temporary Carbon Treatment

<u>Item</u>	<u>Calgon Estimate for 95,000-190,000³/day (25-50 MGD) Module</u>	<u>Estimate for 57,000 m³/day (15 MGD) Module for 25 cm (10 in.) Hydraulic Dredge</u>
Site Preparation	25,000	12,000
Excavation	150,000	73,000
Liner	315,000	153,000
Underdrains & Spillway	320,000	155,000
Gravel	350,000	170,000
Sand	300,000	146,000
Carbon	<u>900,000</u>	<u>437,000</u>
	2,360,000	1,146,000
Engineering	300,000	250,000
Contingency	<u>400,000</u>	<u>200,000</u>
	3,060,000	1,596,000

Design Criteria

Sand Filter Loading - 0.02-0.04 m³/day/m²
(0.5-1 gpm/sf)

Superficial Contact Time - 10-20 minutes

Capital Cost Estimate for Temporary Filtration Only

<u>Item</u>	<u>Estimate for 57,000- 190,000 m³/day (15-50 MGD) Module</u>	<u>Estimate for 57,000 cm³/day (15 MGD) Module for 25 cm (10 in.) Hydraulic Pipeline</u>
Site Preparation	18,000	\$ 1,000
Excavation	100,000	48,000
Liner	200,000	96,000
Underdrains & Spillway	200,000	96,000
Gravel	200,000	96,000
Sand	<u>300,000</u>	<u>\$146,000</u>
	1,018,000	\$491,000
Engineering	150,000	\$100,000
Contingency	200,000	\$100,000
	1,368,000	\$691,000

TABLE 14. Total Costs for Supernatant Treatment with Granular Activated Carbon

<u>Dredge Option</u>	<u>Capital Cost</u>		<u>Days Required</u>	<u>Operating Costs</u>	<u>Total Cost</u>	
	<u>Filtration Only</u>	<u>Carbon Adsorption</u>			<u>Filtration Only</u>	<u>Carbon Adsorption</u>
25 cm (10") Hydraulic Pipeline						
100mg/kg Threshold	\$691,000	\$1,596,000	6	\$1440	\$692,000	\$1,597,000
10mg/kg Threshold	\$691,000	\$1,596,000	16	\$3340	\$695,000	\$1,600,000
1mg/kg Threshold	\$691,000	\$1,596,000	27	\$6480	\$697,000	\$1,602,000
Dozer or						
Pneuma Dredge						
100mg/kg Threshold	\$501,000	\$1,156,000	13	\$3120	\$504,000	\$1,159,000
10mg/kg Threshold	\$501,000	\$1,156,000	37	\$8780	\$510,000	\$1,165,000
1mg/kg Threshold	\$501,000	\$1,156,000	63	\$15,120	\$515,000	\$1,171,000

TABLE 15. Cost of Mobile Carbon Facility for Supernatant Treatment

Pneuma or Dozer Dredged Threshold	Time of Operation (days)	Number of Units Required	Mobilization Costs	Additional Monthly Charge	Operating Costs	Cost Carbons	Total Cost
100mg/kg	12	2	\$100,000	--	\$960	\$24,000	\$125,000
10mg/kg	30	2	\$100,000	--	\$2400	\$24,000	\$126,000
1mg/kg	55	2	\$100,000	5,000	\$4400	\$24,000	\$133,000

TABLE 16. Total Costs for Use of Powdered Activated Carbon for Final Elutriate Treatment

Dredge Option	Volume of Water Treated m ³ /gal	Amount of Carbon Required kg (lbs)	Cost of Carbon	Capacity of Carbon Feeders (kg/day)	Cost of Carbon Feeders	Days of Treatment	Cost of Labor	Total Cost
25 cm Hydraulic Pipeline								
100 mg/kg Dredge Threshold	290,000 (76,000,000)	55,000 (122,000)	\$ 37,000	10,000 (22,000)	\$20,000	6	\$ 1,440	\$ 58,000
10 mg/kg Dredge Threshold	830,000 (220,000,000)	160,000 (352,000)	\$106,000	10,000 (22,000)	\$20,000	16	\$ 3,340	\$130,000
1 mg/kg Dredge Threshold	1,400,000 (375,000,000)	270,000 (600,000)	\$180,000	10,000 (22,000)	\$20,000	27	\$ 6,480	\$206,000
Oozer or Pneuma Dredge								
100 mg/kg Dredge Threshold	34,000 (9,000,000)	4,500 (14,400)	\$ 4,320	540 (1,200)	\$ 1,000	12	\$ 2,880	\$ 8,000
10 mg/kg Dredge Threshold	85,000 (22,500,000)	16,000 (36,000)	\$ 10,800	540 (1,200)	\$ 1,000	30	\$ 7,200	\$ 19,000
1 mg/kg Dredge Threshold	160,000 (41,000,000)	30,000 (66,100)	\$ 19,800	540 (1,200)	\$ 1,000	55	\$13,200	\$ 34,000

requiring disposal. The latter amounts to 340, 1000 and 1700 m³ (450, 1330 and 2200 yd³) (1.3% of total solids) for thresholds of 100, 10 and 1 mg/kg PCB, respectively, with a hydraulic dredge, 40, 98 and 190 m³ (53, 140 and 250 yd³) (0.14% of total solids) for the same thresholds with an Oozer or Pneuma dredge.

Secured Landfill

As noted in the preliminary assessment, use of a secured landfill is one of two disposal options which can be employed on wastes with 50 mg/kg PCB per current proposed TSCA regulations. This option is available at sites which have applied for and received a specific permit under the above mentioned regulations. In certain cases where these options can be shown to be excessively expensive and a less costly alternative can be shown to be environmentally acceptable, the Regional Administrator can grant an exemption from the regulations. Hence, wastes could be buried at an acceptable but formerly unpermitted site.

Several sites in Region V (Figure 32) have historically handled PCB wastes. Since promulgation of TSCA regulations, two have applied for permits to dispose of PCB wastes: 1) Wayne Disposal, Inc., near Dearborn, Michigan, and 2) Earthline, Inc., at Wilsonville, Illinois. Both of these operations have disposed of PCB in the past and claim suitable geologies for such disposal under current regulations. Recent court action has closed the Wilsonville facility at least temporarily, while Wayne Disposal has withdrawn its permit application. A third site operated by Browning-Ferris at Zion, Illinois, has not applied for a TSCA permit, but offers geohydrologic features similar to those of the previously tested sites and offers the advantage of being within 12 miles of the Harbor.



FIGURE 32. Location of Landfills in Relation to Waukegan

Wayne Disposal, Inc., has applied and subsequently withdrawn its application for a permit to allow secured landfill of PCB wastes at its site in Van Buren Township, Wayne County, Michigan. While this site is largely dedicated to disposal of municipal refuse, it was employed for PCB wastes for a period of over 1.5 years. Burial trenches lie in a zone with a 9 to 11 m (30 to 35 ft) of natural clay lying between the surface and the aquifer below. After evaluation by both the state and the local authorities, the site was opened for PCB disposal. Designated PCB wastes were placed in a mini trench in one of the burial cells.

Based on discussions with representatives of Wayne Disposal, Inc., should spoil disposal be directed to this site in the winter of 1979, burial would take place in a location designated in Master Cell No. 4. This is a 360 m (1200 ft) cell with a width of 53 m (175 ft). The natural soil includes a layer of 3 to 3.6 m (10 to 12 ft) of sand over the clay sublayer. Excavations will remove the sand as well as 14 to 16 ft of clay (roughly half of the total thickness). Diversion berms will then be placed across the resultant trench to segment the cell. Fill will be brought to within 0.7 to 1 m (2 to 3 ft) below the clay layer and cover will include 0.7 m (2 ft) of clay. PCB-contaminated sediments will be placed at the bottom of the cell and 20 ft of rubbish placed over that. Each cell will be diked and the dikes keyed into natural clay. Edge drains will be dug to remove perched water which is subsequently discharged to Willow Creek one-half mile downstream.

Based on preliminary information, officials at Wayne Disposal estimate unit disposal costs as outlined in Table 17 (these prices should not be considered a firm bid). In addition, truck transportation to the site from Waukegan would cost \$40/m³ (\$30/yd³). Loading the trucks would add roughly \$1.33/m³ (\$1.00/yd³) (\$32/hr for equipment and operator with an average output of 32/yd³/hr). Total costs for the various options are summarized in Table 18. If reapplication for a PCB disposal permit is not made, use of these sites would require special exemption by the Regional Administrator of EPA.

TABLE 17. Estimated Unit Disposal Costs at Van Buren Township Site

<u>Delivery Rate</u> <u>m³/day (yd³/day)</u>	<u>Winter 1978</u> <u>(m³ (\$/yd³))</u>	<u>Winter 1979</u> <u>\$/m³, (\$/yd³)</u>
770 (1000)	13.71 (10.49)	15.07 (11.53)
380 (500)	15.37 (11.76)	16.92 (12.94)
190 (250)	18.61 (14.24)	20.47 (15.66)
96 (125)	25.15 (19.24)	27.66 (21.16)

TABLE 18. Total Costs for Disposal at Van Buren Township Site

Scenario	Total Spoils m (yd)	Loading Costs	Transportation Cost	Disposal Cost	Total Cost
1000 yd /day Winter 1979					
Dredge Threshold 100 mg/kg	27,000 (35,000)	\$ 35,000	\$1,750,000	\$ 304,000	\$1,490,000
Dredge Threshold 10 mg/kg	78,000 (102,000)	\$102,000	\$3,960,000	\$1,130,000	\$4,340,000
all spoils to site					
Dredge Threshold 10 mg/kg	44,000 (58,000)	\$ 58,000	\$1,740,000	\$ 669,000	\$2,470,000
spoils (PCB) ≥ 50 mg/kg to site					
Dredge Threshold 1 mg/kg	132,000 (173,000)	\$173,000	\$5,190,000	\$1,990,000	\$7,350,000
all spoils to site					
Dredge Threshold 1 mg/kg	49,000 (64,000)	\$ 64,000	\$1,920,000	\$ 738,000	\$2,720,000
spoils (PCB) ≥ 50 mg/kg to site					
500 yd /day Winter 1979	44,000 (58,000)	\$ 58,000	\$1,740,000	\$ 731,000	\$2,550,000
250 yd /day Winter 1979	44,000 (58,000)	\$ 58,000	\$1,740,000	\$ 908,000	\$2,710,000
1000 yd /day Winter 1978	44,000 (58,000)	\$ 58,000	\$1,740,000	\$ 608,000	\$2,410,000
500 yd /day Winter 1978	44,000 (58,000)	\$ 58,000	\$1,740,000	\$ 682,000	\$2,480,000

Earthline Corporation--

The Earthline Corporation Landfill is operated by SCA Services, Inc. at Wilsonville, Illinois. SCA is a national organization specializing in waste management services including those associated with hazardous and nonhazardous chemical wastes. Operation at Wilsonville began on November 15, 1975, under permit from the Illinois Environmental Protection Agency. The site is employed for disposal of a variety of industrial wastes. Recent court action has closed the site, and hence, its status must be considered tentative at this time. The matter is under appeal.

The landfill is situated on a 530,000 m² (130 acre) tract approximately 89 km (55 mi) northeast of St. Louis. Natural soil profiles include a 3-m (10-ft) surface layer of loess underlain by 14 to 20 m (45 to 65 ft) of glacial till with a measured permeability of 10⁻⁸ cm/sec. Sand lenses of 5 to 64 cm (2 to 24 in.) lie in the till materials some 9 to 12 m (30 to 40 ft) below grade. Some of these contain water, but they do not appear to be interconnected. Disposal trenches have a 76 to 107-m (250 to 350-ft) length and 15-m (50-ft) width. They are dug to go 0.3 to 0.6 m (1 to 2 ft) below the loess and never penetrate below 190 m (610 ft) near sea level. This ensures an intermediary layer of 3 to 4.5 m (10 to 15 ft) till above the sand lenses. A drainage channel serves to intercept surface runoff from areas of higher relief. A series of 14 monitoring wells are employed along the perimeter of the property to provide samples from the sand layer for quarterly analysis. Samples are also collected from surface channels. To date, no measurable impacts on water quality have been ascertained.

Historical operating procedures involved containerization of PCB wastes in 210-l (55-gal) drums. These were subsequently stored two high in the trench, face to face, and covered at the end of each working day.

when a trench was filled, it was covered with 0.6 m (2 ft) of clay and one of topsoil gently sloped to diminish rainwater infiltration. PCB were never commingled in the same trench with solvents. The site and its operating practices (with slight modifications to the monitoring program) were found adequate to meet the intent of PCB disposal regulations by an interdisciplinary team of scientists and engineers from the U.S. EPA(a) and State of Illinois (TET).(b) They concluded that:

"...it is the opinion of the TET (Technical Evaluation Team) after considering the design and operational information on the Wilsonville site that it is a well-designed, secure landfill which provides disposal by environmentally acceptable methods and consequently, believe that the facility is capable of managing PCB."

Based on preliminary information concerning the nature of spoils likely to require disposal, Earthline personnel estimate a unit disposal cost of \$110/m³ (\$3/ft³) (including containerization) and a shipping cost of \$545/truck with a rated capacity of 27 m³ (35 yd³) (these are preliminary estimates and should not be interpreted as firm bids). However, gross rate restrictions in Illinois, 33,000 kg (72,000 lb) will put a practical limitation 15 m³ (20 yd³) for spoils with the anticipated consistency of 20 to 25% solids. Once again, loading is estimated at \$1.30 m³ (\$1/yd³) based on \$32/hr for equipment and operator, and a 24 m³ (32 yd³)/hr effective rate. These yield the element and total costs for various disposal scenarios as outlined in Table 19.

(a) United States Environmental Protection Agency, October 1977.

(b) A Technical Report on Earthline Corporation Landfill, Wilsonville, Illinois.

TABLE 19. Total Costs Associated with Disposal at Wilsonville Site

Scenario mg/kg	Total Spoils m ³ (yd ³)	Loading Cost	Transportation Cost	Disposal Cost	Total Cost
Dredge Threshold 100	27,000 (35,000)	\$ 35,000	\$ 953,750	\$ 2,835,000	\$ 3,824,000
Dredge Threshold 10 all spoils to site	79,000 (102,000)	\$102,000	\$2,779,500	\$ 8,262,000	\$11,144,000
Dredge Threshold 10 all spoils (PCB)250 to site	44,000 (58,000)	\$ 58,000	\$1,580,500	\$ 4,698,000	\$ 6,337,000
Dredge Threshold 1 all spoils to site	132,000 (173,000)	\$173,000	\$4,714,250	\$14,014,000	\$18,901,000
Dredge Threshold 1 spoils (PCB)250 to site	49,000 (64,000)	\$ 64,000	\$1,744,000	\$ 5,184,000	\$ 6,992,000

Browning-Ferris Industries, Inc., maintains a private landfill near Zion, Illinois, in the northeast portion of Lake County. The site lies roughly 12 miles north of Waukegan Harbor in a predominately agricultural area. Geologically, the 59+ acres are contained in the relatively high Highland Park End moraine area as mapped by the Illinois State Geological Survey. While Browning-Ferris has not applied for a permit to receive PCB bearing wastes as required by regulations mandated in the Toxic Substances Control Act, its favorable geology and close proximity to Waukegan make it an attractive candidate for disposal of dewatered sediments. At the present time, Browning-Ferris employs the landfill for disposal of municipal and commercial wastes from the town of Waukegan.

Surface drainage at the site is generally parallel to the shore of Lake Michigan as dictated by a series of moraines or ridges which run north and south. Surface soils include 0.15 to 0.06 m (0.5 to 2 ft) of silty and clayey topsoil underlain by tough to hard moderately plastic silty clay containing minor amounts of sand and gravel. Below the 1.5 m (5 ft) level, variable soil conditions exist with interlayered sands, silts and silty clays. This zone extends to depths of 1.8 to 3.9 m (6 to 13 ft) below ground surface. Below these relatively shallow soil layers extends a predominantly low plasticity silty clay with minor amounts of sand and gravel to depths of at least 12 to 16 m (40 to 52 ft) below ground surface (the depth of the borings reported). Irregular seams, pockets and layers of silt, sand and gravel were encountered during borings. Permeabilities are reported at 2×10^{-6} to 1×10^{-8} cm/sec. Only one sample revealed the higher permeability at a depth of 12 to 13 m (40 to 42 ft). Values were an order of magnitude lower in the soil layer above that sample. Cation exchange capability (CEC) of the lower clays has been found to be 5.8 meq/100 g. Ground-water levels are reported to lie at a depth of 3.4 to 5.2-m (11 to 17 ft) below ground surface.

Should a temporary or special permit be approved for disposal of dewatered sediments from Waukegan, burial would be accomplished in an isolated portion of the landfill a minimum of 15 m (50 ft) from the property perimeter and 3 m (10 ft) from any other trench. The minimum barrier thickness would be increased from 3 m to 4.5 to 6 m (10 ft to 15 to 20 ft).

Browning-Ferris estimates unit costs would be $\$33/\text{m}^3$ ($\$25/\text{yd}^3$) for disposal and $\$6.7/\text{m}^3$ ($\$5/\text{yd}^3$) for transportation. Total costs for proposed alternatives are presented in Table 20.

In-Place Fixation

The Takenaka Komuten Co., Ltd, of Japan has developed an applied technology for in-place stabilization of contaminated sediments first reported in 1973. This technology, the Takenaka sludge treatment system

TABLE 20. Total Cost for Disposal at Zion Landfill Site

<u>Scenario mg/kg</u>	<u>Total Spoils m³(yd³)</u>	<u>Loading Cost</u>	<u>Transportation Cost</u>	<u>Disposal Cost</u>	<u>Total Cost</u>
Dredge Threshold 100	27,000 (35,000)	\$ 35,000	\$175,000	\$ 875,000	\$1,085,000
Dredge Threshold 10 all spoils to site	78,000 (102,000)	\$102,000	\$510,000	\$2,550,000	\$3,162,000
Dredge Threshold 10 spoils (PCB)<50 only to site	34,000 (44,000)	\$ 44,000	\$220,000	\$1,100,000	\$1,364,000
Dredge Threshold 1 all spoils to site	132,000 (173,000)	\$173,000	\$865,000	\$4,325,000	\$5,363,000
Dredge Threshold 1 spoils (PCB)<50 only to site	83,000 (109,000)	\$109,000	\$545,000	\$2,725,000	\$3,379,000

(TST system) is available in the U.S. through TJK, Inc., of North Hollywood, California. The process is based on the information of cementaceous-like materials in the natural sediment bed. Portland cement and proprietary additives are mixed into the sediments through a pipe and agitator arrangement at high doses (20% on a wet weight basis) termed the deep chemical mixing (DCM) method. Reagents react and initiate formation of an insoluble silica matrix analogous to concrete with the bed sediments taking the place of aggregate. As the process is repeated, the sediment bed becomes a series of vertical columns side by side like a stack of cord wood standing on end. The compressive strength and stability of this formation has been found adequate to act as a foundation for major construction projects in Japan. If doses are reduced, the fixed sediment takes on properties similar to those of soil or loose aggregate.

As might be expected, in-place fixation can have significant environmental impacts associated with its use. The soluble fraction of reagents added may produce localized effects on biota. Based on laboratory data, major changes in water quality will be related to pH and turbidity. These effects will be minor, however, compared to those on the benthos which will be essentially eradicated as they are encased in fixative. This acute effect will become chronic if navigational considerations dictate against allowing new sediment deposits to accumulate to a point where the benthos can once again thrive. If dosed heavily, the encasement also has major impacts on future changes in channel configuration. Since the bed sediments become concretized, they pose an operational problem for future dredging. Use of cutterheads or other sediment dislodging devices would be eliminated since the hardened sediments would damage them severely. Should greater Harbor depth or dimensions be desired in the future to meet changes in marine transportation needs, it would be extremely difficult to change the configuration of the channel. Indeed, conventional dredging would be totally ineffective on the solidified materials, which militates against use of high dose (20% on a wet weight basis) in favor of formulations producing a soil-like product. However, no data have been found on the leachage characteristics of sediment treated at the lower doses. In the soil-like form, the deposits will once again be transportable via suspension or bed load movement as a result of water currents. This would defeat some of the objectives of fixation, in that sediments would no longer be immobilized in a fixed location.

It should further be noted that work in Japan has been conducted only over the last 5 years. As a consequence, there are no data on the long-term stability of fixed materials. The fixation process utilizes Portland cement and forms a concrete with the sediments as aggregate. If the resulting product resembles high quality concrete, experience indicates that it will be highly durable in aquatic environments over extended periods. However, there is reason to question the degree to which the product will resemble high quality concrete. Studies with various aggregates have shown that the presence of organic contaminants can sacrifice the durability of the product through interference with the normal cement hydration process. This would be of concern in Waukegan Harbor (and the North Ditch) since sediment analysis

has revealed the presence of aquatic weeds, algal matter, detritus, benthic life, and petroleum. ENCOTEC has reported volatile solids concentrations of 3 to 28% in organic carbon levels of 10 to 52 mg/g, and hexane extractables of 140 to 13,000 mg/kg in Harbor sediments. Aluminum and phenol which can also degrade concrete quality were reported at 2300 to 11,200 mg/kg and 1.1 to 31.7 mg/kg respectively. The presence of these materials raises serious questions about the quality of the product and its long-term durability.

It is difficult to make a detailed cost estimate for use of TST technology in Waukegan Harbor. Representatives of TJK, Inc., are reluctant to project costs without performing a site survey and sediment analysis. In general, however, mobilization and demobilization will cost approximately \$100,000. A unit cost of roughly \$17/m³ (\$13/yd³) treated would be added to this figure. Based on these data, total cost will approximate those presented in Table 21.

TABLE 21. Costs Associated with In-Place Fixation of Contaminated Waukegan Harbor Sediments

<u>Action Threshold Level</u> mg/kg (ppm)PCB	<u>Volume Treated</u> m ³ (yd ³)	<u>Mobilization</u> Cost	<u>Operation</u> Cost	<u>Total Cost</u>
100	27,000 (35,000)	\$100,000	\$455,000	\$555,000
10	78,000(102,000)	\$100,000	\$1,330,000	\$1,430,000
1	132,000(173,000)	\$100,000	\$2,250,000	\$2,350,000

Residuals Fixation

As noted earlier, technology for in-place fixation of sediments can also be applied to dredged sediments and a proposed disposal site. This application of stabilization technology was the original arena in which agents were developed and tested. For use on Waukegan Harbor sediments, fixation would require pretreatment to dewater spoils from a hydraulic pipeline dredge. Spoils from the Pneuma or Oozer dredge could be fixed directly. Hence, two modes of operation must be evaluated.

If removal is accomplished by hydraulic pipeline dredge, spoils would be pumped to a dewatering lagoon and supernatant treated and discharged. Subsequently, sediments would be pumped out of the lagoon through a bulk treatment plant where the fixative agent is added, and back to the disposal site. The bulk treatment plant is provided by the contractor as a part of the effort. If a Pneuma or Oozer dredge were employed, fixative agents would be added directly to the dredge discharge line as it was routed to the disposal site. Both options require nearby disposal sites to be cost effective. If sites are distant, disposal could be as easily accomplished at acceptable landfill sites and fixation would not be necessary.

The optimal choice for the disposal site, the only nearby site, is the proposed site for the dewatering lagoon. The lagoon would be constructed for both options since berms are needed to retain sediment during the week required for solidification of the fixed mass. Once complete, a layer of clay would be placed over the fixed sediments and fill dirt to minimize water contact.

As noted earlier, there are major environmental impact considerations associated with in-place fixation. Many of these would be eliminated if fixation were applied to removed sediments at an external disposal site. There would no longer be concern for long-term effects on benthos because the Harbor bottom could return to its natural state after dredging. There would also be less concern for long-term stability related problems since the clay envelope would minimize, if not eliminate, water contact. Potential for weathering and breakdown of the fixed mass would be expected to be significantly less under dry conditions than under submerged conditions as would be encountered with in-place fixation.

The major concern with fixation at the lagoon site would be related to its closeness to Lake Michigan and the legality of disposal at that location. Permits would be required as well as an exemption from TSCA regulations for disposal of PCB. Exemptions would entail some form of proof-of-adequacy which could be a lengthy process. Should leaching occur, it would quickly re-enter Lake Michigan. Ultimately, the fixed mass will form a large, elevated block on the now empty lot. This soil covered plateau would be 1.5 to 1.8 m (5 to 6 ft) high and cover anywhere from 15,000 to 74,000 m² (16,000 to 800,000 ft²) depending on the action threshold selected, i.e., 1, 10, or 100 mg/kg (ppm) PCB. This would severely impact any future development plans for the site. Impacts could be reduced if only sediments with <50 mg/kg (ppm) PCB were fixed and those with ≥50 were buried in a permitted landfill. This option has not been costed at this time.

Representatives of TJK, Inc., are reluctant to provide specific unit cost estimates without the opportunity to run laboratory experiments on sediment samples. However, they have indicated that use of the bulk treatment plant approach would likely cost \$13/m³ (\$10/yd³), while addition of additives directly to pneumatic dredge discharges would cost \$12/m³ (\$9/yd³). The cost of the overseal of clay is estimated as the same as those for the underseal. With the Oozer and Pneuma dredges, lagoon height could be dropped to provide only 1 ft of freeboard. This reduces construction and sealing costs as detailed in Table 22. Cost estimates for Waukegan Harbor are provided in Table 23. Costs could be reduced \$1.3 to 2.7/m² (\$1 to 2/yd³) if sediments do not require high doses of fixative agents (>15% wet weight basis).

Alternatives Comparison

Based on the approaches evaluated in the previous section, there are a total of 35 alternative sequences which could be employed for reduction of

TABLE 22. Reduction in Lagoon Costs With Fixation of Pneuma or Oozer Sediments

Dredge Threshold mg/kg (ppm PCB)	Dimensions, m x m (ft x ft)	Height m (ft)	Berm Volume m ³ /m (yd ³ /linear ft)	Lagoon Volume m ³ (MG)	Cost to Construct	Cost of Seal	Total Cost
100	120 x 120 (400 x 400)	2.4 (8)	5.9 (2.37)	29,000 (10.2)	\$23,000	\$ 69,000	\$ 11,000
10	270 x 150 (900 x 500)	2.4 (8)	5.9 (2.37)	110,000 (28.8)	\$39,000	\$190,000	\$279,000
1	300 x 240 (1000 x 800)	2.4 (8)	5.9 (2.37)	190,000 (51.2)	\$51,000	\$337,000	\$378,000

TABLE 23. Cost of Dredge Spoil Fixation

Alternative (ppm PCB)	Volume of Sediments m ³ (yd ³)	Supplement Treatment Required	Cost of Mobilization	Cost of Fixation	Cost of Cover Seal	Total Cost
Hydraulic Pipeline Dredge						
Dredge Threshold 100 mg/kg	27,000 (35,000)	Yes	\$100,000	\$ 350,000	\$ 35,000	\$ 535,000
Dredge Threshold 10 mg/kg	78,000 (102,000)	Yes	\$100,000	\$1,020,000	\$237,000	\$1,357,000
Dredge Threshold 1 mg/kg	132,000 (173,000)	Yes	\$100,000	\$1,730,000	\$421,000	\$2,251,000
Pneuma or Oozer Dredge						
Dredge Threshold 100 mg/kg	27,000 (35,000)	No	\$100,000	\$ 315,000	\$ 35,000	\$ 500,000
Dredge Threshold 10 mg/kg	78,000 (102,000)	No	\$100,000	\$ 918,000	\$237,000	\$1,255,000
Dredge Threshold 1 mg/kg	133,000 (173,000)	No	\$100,000	\$1,557,000	\$421,000	\$2,078,000

the Waukegan Harbor PCB contamination to a removal threshold of 1 or 10 mg/kg (ppm), and 19 sequences at a threshold of 100 mg/kg (ppm) PCB. The costs for these sequences as compared in Table 24 are ranked from least to most expensive. In-place fixation is clearly the lowest cost alternative. The next lowest cost is associated with fixation at the lagoon site and subsequent sealing with clay. It is clear that disposal costs are the single most dominant factor in determining total costs. Dredging costs are the second most important determinant of total costs, while the addition of carbon adsorption is the least impactful. If fixation is not employed, cost considerations alone dictate that disposal be conducted entirely at the Browning-Ferris landfill in Zion, Illinois, if approval can be obtained. If approval cannot be obtained, all spoils with less than 50 mg/kg (ppm) PCB should be routed to the Zion site and the sediments contaminated above that level should be sent to the approved site. Wayne Disposal, Inc., in Van Buren Township, Michigan, is the lowest cost site of the two evaluated here, but approval would also be required. The SCA site in Wilsonville, Illinois, should be considered only if permits cannot be obtained for the other sites, and then only for the sediments with more than 50 mg/kg (ppm) PCB, if it is reopened by the Courts. Of sites with a current permit for PCB disposal, the closest is in Livingston, Alabama. Similarly, if the reported capacity of the Pneuma is accurate, it is the preferred dredging option followed by the hydraulic suction pipeline, and finally the Oozer. However, the unit costs and removal rate achieved in the Duwamish River operation and in the Cape Fear demonstration suggest that the Pneuma is much more expensive than the hydraulic suction pipeline dredge. Consequently, the latter conventional unit is the dredge of the choice. The differential cost of carbon treatment is small if the Pneuma or Oozer dredges are selected, but significant if a hydraulic suction pipeline dredge is employed.

While costs allow a specific quantitative comparison of alternatives, clearly they cannot serve as the sole basis for selection. There are other factors that are difficult to quantify which must be considered. These have been discussed in previous sections as environmental impacts, legal constraints, and other considerations. A brief synopsis of these factors is provided in Table 25.

Of the three categories of nonquantitative factors, the legal constraints are of the greatest importance. Any alternative found to be outside the current legal framework must be given low priority. While changes in regulation or law may be sought, they cannot be relied upon in the time frame required for near-term resolution of Waukegan Harbor contamination. This is particularly true of the acceptance of fixation. Should fixation be classified by the U.S. EPA as a disposal technology, a change or exemption to TSCA regulations would have to be obtained. Such a change is likely to require an extensive field testing effort which will necessitate delays in restoration of the Harbor. Should the technique be determined to be environmentally acceptable by the U.S. EPA and regulations be modified to accommodate it, fixation would be the least expensive alternative available. Until such decisions are made, however, the approach cannot be recommended for Waukegan Harbor. The option of dry land fixation

TABLE 24. Total Cost of Candidate Alternatives for Waukegan Harbor

Alternative	Segregation by Contamination Level	Carbon Treatment	Disposal	Cost for Threshold		
				1 mg/kg	10 mg/kg	100 mg/kg
In-place fixation	NA	NA	NA	2,350,000	1,430,000	555,000
Hydraulic pipeline	No	No	On-site fixation	3,270,000	1,962,000	795,000
Oozer	No	No	On-site fixation	3,295,000	1,993,000	799,000
Hydraulic pipeline	No	Yes	On-site fixation	3,476,000	2,092,000	853,000
Pneuma	No	No	On-site fixation	3,501,000	2,101,000	813,000
Hydraulic pipeline	No	No	Zion, Ill.	6,395,000	3,776,000	1,351,000
Hydraulic pipeline	No	Yes	Zion, Ill.	6,601,000	3,906,000	1,409,000
Oozer	No	No	Zion, Ill.	6,698,000	3,974,000	1,417,000
Oozer	No	Yes	Zion, Ill.	6,732,000	3,993,000	1,425,000
Pneuma	No	No	Zion, Ill.	6,904,000	4,082,000	1,431,000
Pneuma	No	Yes	Zion, Ill.	6,938,000	4,101,000	1,439,000
Hydraulic pipeline	Yes	No	Wayne Co. & Zion, Ill.	7,149,000	4,459,000	NA
Hydraulic pipeline	Yes	Yes	Wayne Co. & Zion, Ill.	7,355,000	4,589,000	NA
Oozer	Yes	No	Wayne Co. & Zion, Ill.	7,452,000	4,657,000	NA
Oozer	Yes	Yes	Wayne Co. & Zion, Ill.	7,486,000	4,676,000	NA
Pneuma	Yes	No	Wayne Co. & Zion, Ill.	7,658,000	4,765,000	NA
Pneuma	Yes	Yes	Wayne Co. & Zion, Ill.	7,692,000	4,784,000	NA
Hydraulic pipeline	No	No	Wayne Co.	8,382,000	4,954,000	1,756,000
Hydraulic pipeline	No	Yes	Wayne Co.	8,588,000	5,084,000	1,814,000
Oozer	No	No	Wayne Co.	8,685,000	5,152,000	1,822,000
Oozer	No	Yes	Wayne Co.	8,719,000	5,171,000	1,830,000
Pneuma	No	No	Wayne Co.	8,891,000	5,260,000	1,836,000
Pneuma	No	Yes	Wayne Co.	9,925,000	5,279,000	1,844,000
Hydraulic pipeline	Yes	No	Wilsonville & Zion, Ill.	11,421,000	8,326,000	NA
Hydraulic pipeline	Yes	Yes	Wilsonville & Zion, Ill.	11,627,000	8,456,000	NA
Oozer	Yes	No	Wilsonville & Zion, Ill.	11,724,000	8,524,000	NA
Oozer	Yes	Yes	Wilsonville & Zion, Ill.	11,758,000	8,543,000	NA
Pneuma	Yes	No	Wilsonville & Zion, Ill.	11,930,000	8,632,000	NA
Pneuma	Yes	Yes	Wilsonville & Zion, Ill.	11,964,000	8,651,000	NA
Hydraulic pipeline	No	No	Wilsonville	19,933,000	11,758,000	4,090,000
Hydraulic pipeline	No	Yes	Wilsonville	20,139,000	11,888,000	4,148,000
Oozer	No	No	Wilsonville	20,236,000	11,956,000	4,156,000
Oozer	No	Yes	Wilsonville	20,270,000	11,975,000	4,164,000
Pneuma	No	No	Wilsonville	20,442,000	12,064,000	4,170,000
Pneuma	No	Yes	Wilsonville	20,476,000	12,083,000	4,178,000

TABLE 25. Nonquantitative Factors Relevant to the Selection of an Alternative for Waukegan Harbor

Activity	Environmental Impact	Legal Constraints	Other Considerations
REMOVAL AND DISPOSAL			
Pneuma Dredge	Reported to have low solids suspension (recent demonstration did not bear this out); requires disposal and supernatant treatment.	May qualify as foreign and hence be subject to import restrictions.	Unknown mobilization costs. No confirmation of limited data, lack of response to repeated inquiries suggests doubts about availability.
Hydraulic Pipeline	Solids loss higher than pneumatic dredges; requires disposal and supernatant treatment.		May be difficult to operate in the Larsen Marine Basin.
Dozer Pumps	Low solids suspension; requires disposal and supernatant treatment.	May be subject to import restrictions unless Customs allow use of dredge pump on U.S. vessel.	Additional costs of \$40K, plus shipment to Great Lakes, and mobilization on a dredge may not be borne by supplier.
Sedimentation	Residual level of PCB in effluent 1-10 ppb levels.	Will require temporary discharge permit as well as construction permit.	
Carbon Adsorption	Residual level of PCB in effluent .05 ppb.	Will require temporary discharge permit.	Sedimentation required in conjunction with powdered carbon.
Zion, Illinois		Site has not applied for permit; requires special approval.	May be adverse public reaction to use of nonhazardous landfill.
Wayne Co., Michigan	Added risks associated with extensive transportation requirements.	Permit applied for but withdrawn; requires special approval.	Potential adverse public reaction to out-of-state wastes.
Wilsonville, Illinois	Added risks associated with extensive transportation requirements.	Permit applied for but not granted to date; state legal action has had site closed to further use at present time.	Potential adverse public reaction to importation of cross-state waste.
REMOVE AND FIX	Potential long-term effects from breakdown, but maintenance of clay seal should minimize these.	Would require exemption from TSCA regulations and specific permit for site.	Requires long-term commitment of UMC land to creation of a seven foot high plateau, and any future use covenants placed during approval process.
IN PLACE FIXATION	Will eliminate all benthic life. No data available on potential long-term effects, stability. Tradeoff between fixing dimensions of harbor and producing a transportable form of fixed solid.	If defined as disposal, does not comply with TSCA regulations and is therefore illegal.	Lower doses required to allow future harbor maintenance, but data are now available on the retention of PCB's at these lower doses.

offers greatly reduced environmental concerns. As such, it has a better prognosis with respect to acceptance under TSCA regulations. The Earthline landfill at Wilsonville must be considered as unavailable at this time due to recent court action which closed the site.

Similarly, there are legal questions about the use of the Oozer dredge in U.S. waters. Developers hope to satisfy U.S. Customs and Coast Guard requirements by installing the unit on an American vessel. This appears to have been accepted in the case of the Pneuma dredge employed on the Duwamish River. However if this approach is not accepted, use of the Oozer may be precluded. The Pneuma is U.S. owned and operated at this time.

The potential for sediment suspension associated with the hydraulic suction pipeline dredge is greater than that for the Oozer. In the absence of a cutterhead, however, and with the use of the proposed suction head, increased suspensions above those associated with pneumatic systems will be minimal. Further reduction in migration of suspended sediments from the Harbor could be achieved through use of turbidity curtains at a lower incremental cost than that required to operate the Oozer dredge. Placement of these devices is discussed in Section 6. The major effect of suspended sediments will be the extent to which they represent PCB escaping removal. If the suction shroud combined with removal of the cutterhead reduces sediment suspension by an order of magnitude, materials not removed as a result of suspension would approximate 0.04% of the total dredge volume. This is less than potential losses attributed to incomplete coverage of the affected surface area and operation inefficiencies. No acute effects from suspended sediments are anticipated. As a consequence, it is concluded that use of a hydraulic suction piping dredge is the best alternative available at this time.

Given the conclusion that the acceptability of fixation cannot be assured at this time and, hence, that dredging must employed, a means of sediment dewatering and supernatant treatment will be required. Sedimentation without the addition of powdered carbon will involve additional impact in the way of PCB discharges made to Waukegan Harbor. As noted earlier, however, total quantity of PCB discharged will be small, 3 to 14 kg (6 to 30 lb) and may not warrant the large expenditures associated with carbon treatment of supernatant from a hydraulic suction pipeline dredge arrangement (the preferred dredging option). The latter costs would be in the range of \$15000 to \$22,000/kg (\$7000 to 10,000/lb) of PCB removed. Filtration alone has not been considered since it would be more costly than use of powdered carbon.

Review of the geologic, hydrologic and operating features of the three potential disposal sites reveals little difference with respect to their acceptability for disposal of dewatered sediments. However, testimony in recent court action over the Wilsonville site suggests that reported data for that site may have been misleading. Current suspension of operations at Wilsonville suggests that this site may not be available. Neither of the other two sites have applications on file for PCB disposal permits. Although Browning-Ferris has not accepted PCB for disposal at the Zion landfill, discussions with State and Federal officials suggests that a

temporary or special permit could most likely be obtained. Recognition of this probability as well as the lower cost for use of the Zion site and higher potential environmental impacts associated with transportation to the other sites renders the Zion landfill the disposal site of choice. If a special permit is not granted, then spoils should be segregated and those containing <50 mg/kg (ppm) PCB sent to the Zion site while the more highly contaminated sediments shipped to Wayne Disposal, Inc., in Van Buren, Michigan or the nearest permitted site.

In summary, the alternative of choice with the given state of knowledge is use of a hydraulic suction pipeline dredge, followed by dewatering in a sedimentation lagoon and shipment to the Zion landfill. The potential cost reductions available with removal and fixation should not be overlooked. They are substantial enough to warrant an effort to have the alternative permitted under TSCA regulations. If a permit/exemption can be obtained, the preferred option would include removal by hydraulic suction pipeline dredge, dewatering and supernatant treatment in a nearby lagoon, and fixation in the lagoon with subsequent clay overseal. This will also require acceptance by OMC of the topographical changes inherent in placing a 7-ft plateau on their property. Prior to initiation of either course of action, permits would be required for construction of the lagoon, discharge of supernatant, and use of the disposal site. In addition, an environmental impact statement might be required for the overall restoration effort.

THE NORTH DITCH

Three basic approaches for the North Ditch have been identified for detailed evaluation. These options consist of removal of PCB-laden sediments by conventional excavation, or by a Mud Cat dredge, and in-place fixation. If conventional excavation is employed, sediments could be shipped directly to one of three potential disposal sites. If dredging is utilized, sediments would require dewatering and subsequent treatment of supernatant.

Conventional Excavation

While the inflow conditions in the North Ditch are adverse to simple excavation, they are not uncommon in the Waukegan area and based on discussions with consultant and contractors in the area are routinely dealt with during the installation of sewer pipe and other utilities in the area near Lake Michigan. The proposed North Ditch project would include several discrete areas of activity. Cofferdams would be required at the upstream and downstream boundaries of contamination to ensure that surface waters are excluded from the excavation site. Retained water from the upper dam could be piped to Lake Michigan through a temporary bypass or possibly diverted to the Waukegan waste treatment plant storm water lagoons. The latter option would minimize piping costs and should have little impact on the plant. This would have to be approved by the City and the State. Major inflows would be surface runoff and possibly industrial effluent from OMC if the effluent could not be diverted within the plant.

Well point technology would be required to control ground-water inflow. Estimates are not available on the magnitude of associated flows, but well points were successful during sewerline excavation on the north side of the sheet piling on the North Ditch. Since ground water will have been in close contact with heavy PCB contamination, some treatment will be required prior to discharge. Temporary shoring may be required in the area of the cut with backfill applied as quickly as possible to prevent sloughing of the bank. Excavation itself would be conducted with a roadside dragline. Care will also be necessary around the powerpoles on the south shores. Spoils would be loaded into trucks and hauled directly to the disposal site. Covers for trucks and high integrity seals on dump gates would be needed. After discharge of spoils, trucks would be diverted to pick up backfill for the return trip.

Impacts resulting from excavation will be those associated with large-scale excavation projects, including noise and increased traffic. The use of cofferdams should eliminate most of the potential for loss of contaminated sediments into Lake Michigan. Losses may result from further dewatering in trucks and subsequent stop over, but this can be minimized with smaller loads and adequate covers.

A local contractor was contacted to obtain cost estimates for such an undertaking. While experienced in similar excavations in the area, the contractor noted that the uncertainties involved would dictate pricing on a time and materials basis rather than a fixed price bid. However, for purposes of estimation he suggested using an inflated unit cost of \$13/m³ (\$10/yd³) and basing the estimate on a total excavation of as much as 25% greater than the required volume; i.e., if 4800 m³ (6300 yd³) must be removed, assume 6000 m³ (7900 yd³) are handled. Backfill can be estimated at \$4/m³ (\$3/yd³) on the same volume basis, which yields the estimated costs for soil replacement in the North Ditch presented in Table 26. Additional costs for treatment of pumped ground water will be estimated in the section on Supernatant Treatment.

TABLE 26. Cost Estimate for Conventional Excavation of the North Ditch

Removal Threshold mg/Kg (ppm) PCB	Excavation Required m ³ (yd ³)	Actual Excavation Volume For Estimating m ³ (yd ³)	Cost of Excavations	Cost of Backfill	Total Cost
100	2,900 (3,800)	3,700 (4,800)	\$ 48,000	\$14,400	\$ 62,400
10	4,800 (6,300)	6,000 (7,900)	\$ 79,000	\$23,700	\$102,700
1	7,400 (9,700)	9,300 (12,100)	\$121,000	\$36,300	\$157,300

Mud Cat Dredge

Mud Cat dredges have been used at locations where they had to create a channel to float in as they went, although the units work best in 53 cm (21 in.) of water. The Mud Cat could be used to advantage to dredge the contaminated materials from the North Ditch where the sediments are contaminated to a depth of at least 2.1 m (7 ft). Approaching from the Lake or discharge end of the Ditch, for example the dredge could proceed inland cutting its way into the sediments without the need to restrict or redirect the effluent discharge water upstream.

With the adverse slope of the North Ditch in the first 180 m (600 ft) from the mouth, the Mud Cat would have sufficient water depth to remain afloat. Once inside the Ditch, a cofferdam could be constructed to retain flow. This would maintain water in the Ditch and prevent the loss of sediments during the operation. The resuspension of the sediments should not be severe, since the dredge would operate with its turbidity control shroud in the down or protective position. This would ensure that the contaminated sediments and water are drawn directly into the dredge suction for pipeline transportation to the treatment site.

Deadman anchors would be used to gain the forward dredge motion and the dredged material could be pumped directly through the dredge discharge line to the water/sediment treatment facility. Should the distance from the dredging site exceed the dredge's normal pumping distance of 900 m (3000 ft), booster pumps [one pump per 900 m (3000 ft)] could be used to extend the pumping distance. Some labor problems can be anticipated with respect to discharge-pipe handling. This can be overcome by segmenting the work into 60 to 90-cm (200 to 300-ft) cuts and utilizing flexible lines between the dredge and the metal overland discharge pipelines.

In the areas of the ditch where a deeper cut is required [0.9 to 2.1 m (3 to 7 ft)], a sheer bank of mud will be created on the south shore where the private OMC road serves the adjacent parking facilities. Without support, the road will be undermined by erosive water action. This suggests the need for temporary shoring. Alternately, traffic patterns could be rerouted and the bank allowed to shift to a more easily maintained 1:1 slope. Backfill and repaving would then restore the roadway. From the preliminary engineering review, this alternative appears to be less expensive than the use of structural shoring. Ample shoulder is available on most of the south bank to accommodate the removal of as much as 0.9 m (3 ft) of sediment without threatening the roadway or power lines. The 300 ft requiring a 2.1 m (7 ft) cut lie in the western end of the Ditch above the road crossing. It is not known if any structures lie close the Ditch in this section. In either event, a limited amount of shoring or structural support would be advisable in this reach, as well as support wires for all power poles. In all locations, backfill should be trucked to the Ditch and applied behind the Mud Cat to minimize erosion. The dredge would be retired from the Ditch by crane after completion of work.

The upper 90 m (300 ft) of contaminated ditch lie on OMC property, upstream of the culvert beneath the private road crossing. This segment has not been available for survey. However, the presence of the culvert would prevent access by the Mud Cat, and as a consequence, this portion would likely have to be excavated with a bank side dragline or other suitable excavation equipment.

Use of a Mud Cat dredge will result in environmental impacts associated with suspension of sediments and the need for rerouting or restricting traffic to a single lane on the OMC road for a brief period. The use of the dredge's turbidity control shroud and the downstream coffer should prevent any migration of sediments or contamination into Lake Michigan. Hence, the major impact of sediment suspension will relate to the degree to which it represents unretrieved contamination subsequently left in place.

Costs for the Mud Cat dredge are based on a monthly rental charge of \$13,000 for a minimum 2-month period. Costs for shipment, operation crews, loading and unloading and auxiliary equipment are estimated at \$48,000. Backfill would be required at a unit cost of \$4/m³ (\$3/yd³), as would an earthen cofferdam of 11 m³ (14 yd³) at a unit cost of \$6.7/m³ (\$5/yd³). Resurfacing of the road, should erosion be sustained, is estimated at \$10,000. Costs for excavation of the 90 m (300 ft) portion of Ditch above the road crossing cannot be estimated at this time. Total costs for the proposed approach are given in Table 27.

TABLE 27. Costs Associated with Use of the Mud Cat Dredge to Excavate the North Ditch

Dredge Threshold mg/Kg (ppm) PCB	Excavation Required m ³ (yd ³)	Cost of Dredging	Cost of Coffer Dam	Cost of Backfill	Cost of Resurfacing	Total Cost
1	7,400 (9,700)	\$48,000	\$100	\$29,000	\$10,000	\$86,000
10	4,800 (6,300)	\$48,000	\$100	\$19,000	\$10,000	\$77,000
100	2,900 (3,800)	\$48,000	\$100	\$11,000	\$10,000	\$69,000

(a) Some savings in labor costs would be realized for the higher dredging threshold cases due to the shorter length of project duration. However, the uncertainty associated with overdredging in a project of this size mitigates against calculating these savings.

Due to the need for continual pipeline handling and potential mechanical downtime, a low dredge production rate of 30 m³/hr (40 yd³) is estimated. At that rate, dredging would require 95, 158 and 243 hr for the three potential dredging thresholds. Consequently, no more than 30 days (at 8 hr/day) would be required for excavation. This would leave an additional 30 days on the rental agreement for the Mud Cat. As noted

previously, the dimensions of the Larsen Marine Boat Basin and presence of pilings will pose operational problems for the larger dredges proposed for restoration of Waukegan Harbor, while the Mud Cat would be ideal for operation in the boat basin. With an additional 30 days available on the rental agreement, this craft could be utilized in place of the larger dredge. Additional costs would amount to $\$1.3/\text{m}^3$ ($\$1/\text{yd}^3$) of sediment removed. Hence a reduction of $\$2.7/\text{m}^3$ ($\$2/\text{yd}^3$) would be realized over operation of the large dredges for the approximately 2300 m^3 (3000 yd^3) of sediments in the slip area. After adjustment for crane rental to mobilize and demobilize and incidental costs, a total savings of $\$5000$ is likely. This reduction would not be realized if conventional excavation were employed in the North Ditch

Supernatant Treatment

The options available for supernatant treatment have been discussed at length in the previous section on Waukegan Harbor. Cost considerations and the need to dewater dredged sediments dictate use of a settling lagoon. If additional PCB removal is required, it is most cost effectively accomplished through addition of powdered activated carbon to the pipeline discharge. Filtration alone could be employed, but is more costly than the addition of powdered activated carbon.

Restoration of the North Ditch will also produce water requiring treatment if in-place fixation is not employed. In the case of conventional excavation, water from the well point operation would be pumped to the treatment. It is difficult to estimate the volume of these waters, but it is likely to be less than $190 \text{ m}^3/\text{day}$ ($50,000 \text{ gpd}$) over a maximum of 20 days. If the Mud Cat dredge is employed in the Ditch, hydraulic transport water (10:1 ratio to sediments excavated) will require treatment. No costs are allocated for the settling lagoon itself since more than ample capacity is available. Costs are attributed only to the cost of polymer and carbon which have a unit cost of $\$0.06$ and $\$0.15/\text{m}^3$ ($\$0.000023$ and $\$0.00055/\text{gal}$) treated. Consequently, incremental costs associated with water treatment are calculated as presented in Table 28.

Disposal

Three sites have been identified with the potential for handling PCB-contaminated sediments. A discussion of these sites appears in the preceding section on Waukegan Harbor. Costs associated with sediments from the North Ditch can be calculated on the basis of the same unit costs discussed above. If conventional excavation is employed, sediments can be directly hauled to the site. If the Mud Cat dredge is employed, sediments would be hauled from the settling lagoon. Total costs associated with disposal are provided in Tables 29 through 31.

TABLE 28. Costs Associated with Treatment of Water During Restoration of the North Ditch

<u>Removal Mode (ppm) PCB</u>	<u>Total Volume of Water m³ (gal)</u>	<u>Cost of Polymer</u>	<u>Cost of Carbon</u>	<u>Total Cost With Carbon Treatment Options</u>
Conventional Excavation				
Threshold 100 mg/Kg	3,800 (1,000,000)	\$ 23	\$ 550	\$ 570
Threshold 10 mg/Kg	3,800 (1,000,000)	\$ 23	\$ 550	\$ 570
Threshold 1 mg/Kg	3,800 (1,000,000)	\$ 23	\$ 550	\$ 570
Mud Cat Dredge				
Threshold 100 mg/Kg	29,000 (7,600,000)	\$175	\$ 4,180	\$ 4,400
Threshold 10 mg/Kg	48,000 (12,600,000)	\$290	\$ 6,930	\$ 7,200
Threshold 1 mg/Kg	74,000 (19,400,000)	\$446	\$10,700	\$11,000

TABLE 29. Total Costs Associated with Disposal at Wayne County Site

<u>Scenario (ppm)</u>	<u>Spoils m³ (yd³)</u>	<u>Loading Costs</u>	<u>Transportation Cost</u>	<u>Disposal Cost</u>	<u>Total Cost</u>
Winter 1979 - 1000 yr ³ /day					
Excavation at 100 mg/Kg	3,700 (4,800)		\$144,000	\$ 55,000	\$199,000
Excavation at 10 mg/Kg	6,000 (7,900)		\$237,000	\$ 91,000	\$328,000
Excavation at 1 mg/Kg	9,300 (12,100)		\$363,000	\$139,000	\$502,000
Dredge at 100 mg/Kg	2,900 (3,800)	\$3,800	\$114,000	\$ 44,000	\$162,000
Dredge at 10 mg/Kg	4,900 (6,300)	\$6,300	\$189,000	\$ 72,000	\$267,000
Dredge at 1 mg/Kg	7,400 (9,700)	\$9,700	\$291,000	\$112,000	\$413,000

TABLE 30. Total Costs Associated with Disposal
at Wilsonville Site

<u>Scenario (ppm)</u>	<u>Total Spoils m³ (yd³)</u>	<u>Loading Cost</u>	<u>Transportation Cost</u>	<u>Disposal Cost</u>	<u>Total Cost</u>
Excavation at 100 mg/Kg	3,700 (4,200)		\$131,000	\$389,000	\$ 520,000
Excavation at 10 mg/Kg	6,000 (7,900)		\$215,000	\$640,000	\$ 955,000
Excavation at 1 mg/Kg	9,300 (12,100)		\$330,000	\$480,000	\$1,310,000
Dredge at 100 mg/Kg	2,900 (3,900)	\$3,800	\$104,000	\$308,000	\$ 416,000
Dredge at 10 mg/Kg	4,300 (6,300)	\$6,300	\$172,000	\$510,000	\$ 688,000
Dredge at 1 mg/Kg	7,400 (9,700)	\$9,700	\$254,000	\$786,000	\$1,060,000

TABLE 31. Total Costs Associated with Disposal
at Zion Landfill Site

<u>Scenario (ppm)</u>	<u>Total Spoils m³ (yd³)</u>	<u>Loading Cost</u>	<u>Transportation Cost</u>	<u>Disposal Cost</u>	<u>Total Cost</u>
Excavation at 100 mg/Kg	3,700 (4,800)		\$24,000	\$120,000	\$144,000
Excavation at 10 mg/Kg	6,000 (7,900)		\$39,500	\$197,000	\$237,000
Excavation at 1 mg/Kg	9,300 (12,100)		\$60,500	\$302,500	\$363,000
Dredge at 100 mg/Kg	2,900 (3,800)	\$ 3,800	\$19,000	\$ 95,000	\$118,000
Dredge at 10 mg/Kg	4,800 (6,300)	\$ 6,300	\$31,500	\$158,000	\$196,000
Dredge at 1 mg/Kg	7,400 (9,700)	\$ 9,700	\$48,500	\$243,000	\$301,000

In-Place Fixation

The use of in-place fixation has been discussed in the previous section on Waukegan Harbor. Representatives of TJK, Inc., the American marketing agent for the TST system, indicate that the same equipment and costs apply to shallow areas such as the North Ditch and harbors. The mixing equipment is mounted on pontoons and has been employed in tidal flat areas where no standing water was present.

Once again, the impacts associated with this alternative are related to the elimination of benthic life and the unknown potential for long-term release. No benthic life has been found in recent bottom sampling, and long-term stability can be postulated from leachate tests; however, implications over the life of persistent materials, such as PCB are unknown. Concerns noted in the previous section on Waukegan Harbor would be heightened here because of the generally higher level of organic materials in the North Ditch sediments.

Unit costs for application of fixative agents include mobilization-demobilization costs of \$100,000 and an operational expense of \$17/m³ (\$13/yd³). If fixation is employed in the Harbor as well, the mobilization costs would not apply. Total costs for in-place fixation of sediments in the North Ditch are presented in Table 32.

Residual Fixation

As noted previously, fixation can be conducted on dredged sediments to allow disposal at the site of the lagoon and thereby eliminate the costs of transportation and commercial disposal. The details and implications of this approach were presented in the preceding section on Waukegan Harbor. Incremental unit costs are estimated to be \$13/m³ (\$10/yd³). Costs of the lagoon and clay seal are neglected since these will be borne in meeting the needs of Waukegan Harbor. Sufficient capacity will exist to manage the additional 10% of sediments removed from the North Ditch. Incremental costs are presented in Table 33. Mobilization costs of \$100,000 still apply.

Comparative Analysis

The feasibility of two basic removal technologies, conventional excavation and dredging with a Mud Cat, the option for sedimentation treatment of water with or without carbon addition, and the potential availability of three disposal sites in addition to fixation yield a total of 20 discrete alternative restoration programs for the North Ditch. Each sequence is listed in order of increasing total cost in Table 34.

As with restoration of Waukegan Harbor, in-place fixation is the lowest cost alternative available. If removal is necessitated, the excavation technique is the overriding cost factor at the low threshold levels (1 mg/kg PCB) while disposal costs predominate at higher action levels (10 to 100 mg/kg PCB). This cross over is a consequence of the fixed rental fee

TABLE 32. Cost of In-Place Fixation of North Ditch

<u>Treatment Requirement</u>	<u>Sediment Volume m³ (yd³)</u>	<u>Cost of Fixation</u>	<u>Mobilization Cost</u>	<u>Total Cost</u>
(Waukegan Harbor Dredged)				
Threshold 100 mg/kg	2900 (3800)	\$ 49,400	\$100,000	\$149,000
Threshold 10 mg/kg	4800 (6300)	\$ 81,900	\$100,000	\$182,000
Threshold 1 mg/kg	7400 (9700)	\$126,100	\$100,000	\$226,000
(Use of Fixation in Waukegan Harbor also)				
Threshold 100 mg/kg	2900 (3800)	\$ 49,400	-	\$49,000
Threshold 10 mg/kg	4800 (6300)	\$ 81,900	-	\$82,000
Threshold 1 mg/kg	7400 (9700)	\$126,100	-	\$126,000

TABLE 33. Incremental Costs Associated with Residuals Fixation
After Dredging the North Ditch

<u>Removal Threshold mg/kg (ppm) PCB</u>	<u>Volume of Sediments m³ (yd³)</u>	<u>Total Cost(a)</u>
Mud Cat Dredge		
100	2900 (3800)	\$ 38,000
10	4800 (6300)	\$ 63,000
1	7400 (9700)	\$ 97,000
Roadside Excavation		
100	3700 (4800)	\$ 48,000
10	6000 (7900)	\$ 79,000
1	9300 (12100)	\$121,000

- (a) Assumes only incremental costs of fixation; lagoon or seal required for Waukegan sediments will have adequate capacity for these materials.

**TABLE 34. Total Cost of Candidate Alternatives
for the North Ditch**

Removal	Powdered Carbon Addition	Disposal Site	Cost for Threshold		
			1 mg/kg	10 mg/kg	100 mg/kg
In-Place Fixation (Harbor fixed also)			126,000	82,000	49,000
Mud Cat	No	On site fixation (Harbor fixed)	183,000	140,000	107,000
Mud Cat	Yes	On site fixation (Harbor fixed)	194,000	147,000	111,000
Conventional excavation	No	on site fixation (Harbor fixed)	278,000	182,000	110,000
In-Place Fixation (Harbor dredged)			226,000	182,000	149,000
Mud Cat dredge	No	On site fixation (Harbor dredged)	283,000	240,000	207,000
Mud Cat dredge	Yes	On site fixation (Harbor dredged)	294,000	247,000	211,000
Conventional excavation	No	On site fixation (Harbor dredged)	378,000	282,000	210,000
Mud Cat dredge	No	Zion, Ill.	387,000	273,000	187,000
Mud Cat dredge	Yes	Zion, Ill.	398,000	280,000	191,000
Mud Cat dredge	No	Wayne County	499,000	344,000	231,000
Mud Cat dredge	Yes	Wayne County	510,000	351,000	235,000
Conventional excavation	No	Zion, Ill.	520,000	340,000	206,000
Conventional excavation	Yes	Zion, Ill.	521,000	341,000	207,000
Conventional excavation	No	Wayne County	659,000	431,000	261,000
Conventional excavation	Yes	Wayne County	660,000	432,000	262,000
Mud Cat dredge	No	Wilsonville	1,146,000	765,000	485,000
Mud Cat dredge	Yes	Wilsonville	1,157,000	772,000	489,000
Conventional excavation	No	Wilsonville	1,467,000	958,000	582,000
Conventional excavation	Yes	Wilsonville	1,468,000	959,000	583,000

for the Mud Cat dredge. The combined effect of these factors renders the Mud Cat dredge with onsite fixation the lowest cost alternative. If fixation cannot be accomplished, disposal should be directed to the landfill at Zion, Illinois. If the Zion landfill is not approved, disposal should be directed to Wayne Disposal in Van Buren, Michigan. In no case would conventional excavation be preferred. Once again, Wilsonville is the most expensive disposal option. Use of powdered carbon increases costs only slightly (\$1,000 to 11,000).

Cost is only one of the factors which must be considered in selecting a preferred approach. Other important factors include those pertaining to environmental impacts, legal constraints, and other considerations. A synopsis of these factors relevant to the candidate alternatives is provided in Table 35.

The legal constraints stand as the most important factors relevant to selection of alternatives, since they may eliminate a candidate completely. Obtaining the permits for construction, dredging, etc., which will be required does not appear to be a major obstacle at this time, however. Contact with both State and Federal representatives has confirmed that the lack of PCB disposal permits at this time is not an indication of adverse finding, and that disposal sites should be available when needed (except the Wilsonville site, which has been closed through legal action). Similarly, construction and discharge permits should not be difficult to obtain. The greatest potential legal impact rests with interpretation of TSCA disposal regulations and fixation. Should fixation be considered as a method of disposal, that alternative would not be legal at this time. A discussion of this issue has been presented in the previous section on Waukegan Harbor.

In some respects questions concerning the legality of fixation are based upon limited knowledge of long-term stability of the stabilized mass. If a breakdown of the fixed bed occurs in the future, fixation offers little more than a holding action. The contamination is transferred from an imminent to a latent threat. These issues are of particular concern in the North Ditch since this wasteway carries both industrial wastes and storm runoff. Either of these can contain low pH waters; e.g., rain in industrial areas has been measured at pH 4.5 and below. These conditions are known to cause breakdown of composites stabilized by the TST system.

Environmental impacts of the candidate approaches other than fixation could result principally from transportation of large quantities, (2,000 to 10,000 truckloads) of contaminated sediments to the more distant disposal sites. In addition, approximately 4.5 to 6.8 kg (10 to 15 lb) of PCB would be discharged in lagoon effluent without powdered carbon treatment. Remaining considerations, such as public reaction to burial of wastes on land, reinforce the preference among alternatives suggested by cost considerations, i.e. in-place fixation.

TABLE 35. Nonquantitative Factors Relevant to Selection of an Alternative for the North Ditch

<u>Activity</u>	<u>Environmental Impact</u>	<u>Legal Constraints</u>	<u>Other Considerations</u>
REMOVAL AND DISPOSAL			
Conventional excavation	Noise, traffic, potential loss of sediments and/or contaminated water from stop over in trucks, need to disrupt roadway, requires disposal.	Most require construction permit.	Contractors reluctant to give a firm bid, would only undertake on time and material basis.
Mud Cat dredge	Need to disrupt roadway, requires disposal.		May be unable to address portion of ditch upstream of the road crossing, could be used to improve dredging of Larsen Marine Boat Basin at minimal cost.
Sedimentation	Residual level of PCB in effluent, 1-10 ppb range.	Requires construction and discharge permit.	Facilities already built if harbor is dredged.
Powdered carbon adsorption	Residual level of PCB in effluent 0.05 ppb.	Requires discharge permit.	Requires sedimentation lagoon, equipment on hand if harbor is dredged.
Zion landfill		Would require special permit.	May be adverse public reaction to use of a nonhazardous landfill.
Wilsonville landfill	Added risk due to transportation distance required.	Permit applied for - site closed by court action.	May be adverse public reaction to import of cross-country wastes.
Wayne County landfill	Added risk due to transportation distance required.	Permit applied for and subsequently withdrawn - would require special permit.	May be adverse public reaction to import of out of state wastes.
REMOVE AND FIX			
	Potential effects from long term breakdown, but clay seal should minimize these.	Would require exemption from TSCA and permit for site.	Requires long term commitment of OMC land to covenants included in approval process.
IN-PLACE FIXATION			
	Elimination of benthic life, unknown potential for chronic leaching of PCB's, unknown long term stability, low pH waste paper and/or acid rain will accelerate breakdown of the fixed sediments.	If designated as a disposal technology, would not comply with TSCA regulations.	No data are available on long term stability which may be directly affected if acid conditions occurs in the ditch, stabilized sediments would serve to minimize erosion. Potential adverse public reaction to leaving sediments in place.

Based on continued uncertainty over the legal and most particularly, the environmental status of fixation, it is concluded that the preferred alternative for the North Ditch is use of the Mud Cat dredge and disposal in the Browning-Ferris landfill in Zion, Illinois. The comparative cost of powdered carbon treatment of supernatant is small; however, the minor amount of PCB discharge which would be eliminated may not be considered sufficient to justify that cost. If permits cannot be obtained for the Zion site, dewatered sediments should be shipped to Wayne Disposal, Inc. in Van Buren, Michigan. The large savings possible if onsite fixation can be employed warrant some additional effort. Exemptions for this disposal option should be pursued. If approval can be obtained in a timely manner, the preferred alternative will be the Mud Cat dredge and onsite fixation at the proposed dewatering lagoon.

SECTION 6

IMPLEMENTATION OF RECOMMENDATIONS

Based on the detailed evaluation, it is concluded that removal, treatment and disposal of contaminated sediments in Waukegan Harbor and the North Ditch is the best means of restoration available at this time. While in-place fixation is the low cost alternative, questions concerning the legality and long-term environmental implications mitigate against its use. Similarly, a lack of confirmed data on costs, capabilities, and the availability of the Pneuma dredge dictate use of a more conventional and readily available hydraulic suction pipeline dredge in the Harbor. Should more definitive data be located and/or the status of the fixation or Pneuma technology be determined to be acceptable, these recommendations could be altered significantly. This could, however, require a period of years of observation of fixation projects undertaken in Japan, whereas the Waukegan Harbor contamination warrants early corrective action.

WAUKEGAN HARBOR

The preferred alternative for restoration of Waukegan Harbor involves dredging and then dewatering spoils in a sedimentation lagoon, and burial at a nearby sanitary landfill. Pertinent considerations for conducting the required removal, treatment and disposal activities are summarized below.

Removal

Equipment and Manpower Requirements--

A 25 or 30-cm (10 or 12-in.) hydraulic pipeline dredge should be contracted to conduct the main dredging operation. The selected dredge should be supported by a Mud Cat dredge that can enter the Larsen Boat Yard slip to dredge within the confines of the area and clear the contaminated sediments from between the pleasure craft piers. While the dredging of the Larsen slip is under way the movable decking should be removed to provide as much open access to the area as practical.

The main dredge should be supported by a substantial crane barge and a work boat with sufficient power to act as a tug for dredge positioning and to adequately (with crane barge assistance) position and recover the dredge swing anchors.

The cost per cubic yard dredged includes the labor cost. The hydraulic pipeline dredge crew would, however, consist of at least three fully experience levermen (dredge operators), three deckhands and three pipeline discharge attendants. The pipeline workers, with assistance from the workboat crew, would be responsible for positioning the discharge pipeline and adding additional pipe sections to meet the demands of dredging progress. Such a staff would permit a three-shift operation to develop a 24-hr work day. The crew assigned to the hydraulic pipeline dredge would also operate the Mud Cat dredge once the main dredging operation was completed.

Safety and Environmental Precautions--

The following safety precautions should be exercised during the entire length of the dredging project:

American General Contractors of America, Inc., Safety Standards

- Each work craft should have a ladder leading from deck level to water level.
- During the night hours sufficient illumination should be provided to gain full visibility of all deck spaces and the immediate water surface surrounding the dredge.
- Each work craft should have at least one life ring on the port and starboard side of the vessel ready for immediate emergency use. The ring should have at least 15 m (50 ft) of substantial life line attached to same.
- Life preservers should be provided in accordance with U.S. Coast Guard Regulations. All plants should be equipped with U.S. Coast Guard approved ring buoys spaced at not less than 50-ft intervals. U.S. Coast Guard approved work vests should be worn by all personnel working on floating pipelines, on barges and floating plants and protected by handrails, no structures extending over waters, over the side of any vessel, or alone at night in areas where a drowning hazard exists.

Work vests should be designed to float helpless persons face up.

Work vests should be examined in frequent intervals to assure that they are in good working condition.

- Whereas PCB is normally not considered acutely toxic to humans through inhalation, oral ingestion, or dermal exposure, short-term irritation and long-term health effects are possible from prolonged needless exposure to the material. Excessive exposure would warrant occupational health safeguards to avoid physical contact with the contaminant. In this respect, pump and pipeline leaks should be promptly controlled and workers handling the discharge pipe should wear protective clothing to avoid skin contact.

NOTE: DOT/OSHA presently have no specific regulations pertaining to dredge workers however all applicable regulations contained in "General Industry and Health Standards - OSHA 2206(29 CFR 1910) revised January 1976 would apply to the project.

Dredge Navigation Requirements

The USCG requirements as contained in CFR 33 90.24 through 90.34 with respect to navigation lighting for dredges and pipelines and the buoying of moorings should be adhered to for the duration of the dredging project. Additionally, all Federal regulations applicable to dredges, tugs, and barges contained in CFR 46 regarding fire fighting equipment, manning and handling of hazardous materials should be followed for the duration of the work project.

Environmental Precautions

- The discharge pipeline should be inspected on a regular basis to ensure that no joint leakage is evident that would discharge PCB-contaminated sediments into water suspension.
- The depth of dredge cut should be regulated as closely as possible to avoid: 1) excessive digging beyond the capability of the suction, and 2) over dredging beyond the known contamination limit.
- When practical a full turbidity curtain should be used to contain solids placed into water suspension from dredging, anchoring and tug operation. Such a measure would be particularly effective at the Harbor entrance and the mouth of Slip No. 1, and in the Larsen Marine Service, Inc. pleasure boat basin. It is understood that a turbidity curtain may be made available for selected use on this project from the U.S. EPA Edison Laboratories.
- Dredging equipment should be cleared subsequent to use on heavily contaminated sediments. This is best achieved through pumping of "clean" sediments after contaminated areas have been cleared.

Sampling and Monitoring Requirements—

Background water samples should be recovered prior to commencement of dredging operations from known areas of PCB contamination. (Slip 1, Slip 3, an intermediate zone between the two slips, east of the Yacht Club, and the channel entrance.) The samples should be analytically examined by predictive tests such as the "Standard Elutriate Test" and "Interstitial Water Evaluation Test" to determine the PCB contamination level. As dredging progresses in the area of each background sampling station, further water testing should be undertaken for comparison purposes at each anchorage, specifically to gain knowledge of any increase in pollutants in the water column as a result of the dredging activity. Should an increase be detected the dredging rate should be reduced to decrease the turbidity plume.

Post dredging sampling is also required to ascertain the effectiveness of the removal effort. This would require eight evenly distributed samples: one in each slip, one between the slips, one at the mouth of Slip 1, one at each end of the channel and two in the area east of the Yacht Club. The estimated cost of sampling and analysis is \$10,000.

Time Needed for Completion--

To avoid interference with waterborne traffic and the mooring of pleasure craft, it would, weather permitting, be advisable to conduct the harbor dredging operations between October 1 of one year and May 1 of the following year. To exclude obvious bad weather months all equipment should be assembled, ready for use prior to October 1 to provide 2 full months (October and November) to complete the operation. The alternative would involve equipment assembly prior to March 1 to gain advantage of the two early spring months (March and April). On this basis all pleasure craft would, according to the harbor master, be out of the water and in dry land storage during the selected work period.

Arrangements would have to be made with the users of Slip No. 1 to stockpile materials in advance to eliminate barge and tug traffic in and out of the slip during the selected dredging period. Additionally, to provide as much free movement as possible within the Larsen Marine Service Inc. pleasure boat slip, the pier decking should be removed. Since the decking is designed for removal as protection against ice damage this requirement should present no major problem. Mud Cat dredging of Slip 3 should be accomplished first since this is the most heavily contaminated zone. Any suspended sediments from this operation would then be subject to settling and possible removal when the hydraulic pipeline dredge is brought in. Once necessary arrangements have been made the time estimates for dredging should be approximately as follows:

- Surficial dredging of 27,000 m³ (35,000 yd³) to reduce contamination level to 100 mg/kg (ppm) - 6 days.
- Removal of 78,000 m³ (102,000 yd³) to reduce contamination level to 10 mg/kg (ppm) - 16 days.
- Removal of 132,000 m³ (173,000 yd³) to reduce contamination level to 1 mg/kg (ppm) - 27 days.

The time factor depends on weather conditions, mechanical downtime, dredge pumping capacity, and, of greater importance, the ability of the contaminated soil and water treatment facility to meet the pumping rate of the dredge.

Estimated Cost Based on Elimination of Sediments at Levels 100, 10, and 1 mg/kg (ppm)--

Removal of 27,000 m³ (35,000 yd³) of Dredge Material

Direct dredging cost at \$5.3/m ³ (\$4 yd ³)	- \$ 140,000
Design and Engineering at 20% of direct cost	- 28,000
Tug services at \$2200/day/6 days	- 13,200
Crane rental (min. 4 hr rental)(a) 1 day	- 360
	<u>\$ 181,560</u>

NOTE: Cost of Mud Cat dredge is not included in estimate since this cost would be included in North Ditch dredging cost. This condition would apply to both estimates which follow.

Removal of 78,000 m³ (102,000 yd³) of Dredge Material

Direct dredging cost at \$4/m ³ (\$3.00/yd ³)	- \$ 306,000
Design and engineering at 20% of direct cost	- 61,200
Tug services at \$2200/day/16 days	- 35,200
Crane Rental	- 360
	<u>\$ 402,760</u>

Removal of 132,000 m³ (173,000 yd³) of Dredge Material

Direct dredging cost at \$4/m ³ (\$3.00 yd ³)	- \$ 519,000
Design and engineering at 20% of direct cost	- 103,800
Tug services at \$2200/day/27 days	- 59,400
Crane rental	- 360
	<u>\$ 682,560</u>

NOTE: Cost of the Mud Cat dredge recommended for dredging the Larsen pleasure boat slip is included in the North Ditch restoration costs which follow.

IMPORTANT NOTE: The final dredging cost can be influenced by the site of the proposed water/solid treatment facility. Should the treatment site be remote from the dredging location the provision and installation of additional discharge pipeline and booster pumps could increase the costs for each pipe section and booster unit required to meet the transportation demands. Until a site is selected the additional cost cannot be estimated.

(a) Crane would be used to raise and lower Mud Cat dredge into and out of water.

Treatment

Equipment and Manpower Requirements—

Treatment should be accomplished through use of a sedimentation lagoon located on OMC property east of the north end of Waukegan Harbor and adjacent to the public beach. The lagoon should be constructed of earth fill placed above grade after initial clearing of the top 0.3 m (1 ft) of soil and vegetation. Soil is to be compacted until a berm formed with a 6 m (20 ft) base, and equally sloping sides to a height of 3 m (10 ft). These should form a rectangle with dimensions of 120 x 120 m (400 x 400 ft), 270 x 150 m (900 x 500 ft), or 300 x 240 m (1000 x 800 ft), depending upon selection of a dredge threshold of 100, 10 or 1 mg/kg (ppm) PCB, respectively. Reinforcement should be provided in the northwestern corner of the lagoon to accommodate support of the influent pipeline. An overflow weir capable of flows of 57,000 m³ (15 MGD) should be constructed in the southeast corner of the lagoon with a retained height of 2.7 m (9 ft). The weir should feed a header box connected to an appropriately sized effluent pipe routed back to the Harbor. A stationary boom device should be installed to protect the weir from floating scums. The bottom and walls of the lagoon should be sealed with an impermeable layer of clay with characteristics equivalent to those of bentonite.

Implementation will require receipt of a construction and discharge permit for the lagoon. Equipment requirements will include sheepsfoot packer, a wheeled scraper and a front-end loader. Fill for the dike may be imported or purchased from the OMC stockpile on the western border of the proposed lagoon site. The U.S. Corps of Engineers estimates that 554,000 cm³ (70,000 yd³) of sediments have been deposited here, which is more than required for constructing the lagoon. Manpower requirements include operators for the equipment and two carpenters to construct the spillways over the 2.7 m (9 ft) weir section and the header box. Carpenters should also construct or position an (rented) enclosure for storage and mixing of polymer additives. Effluent water would be employed to produce a 10:1 slurry for injection into the pipeline effluent. A 1900 l (500 gal) tank, mixer and pump will be required. An operator will be required to mix polymer solution, check equipment and maintain facilities on a 2-hr per shift basis. Upon completion of dredging, a full-time operator would be required to maintain dewater pumps.

A blade will be required after completion of removal activities to remove the berms and otherwise decommission the facility. If clay layers are buried with contaminated sediments, the residual berm materials should not require any special treatment.

Safety and Environmental Precautions—

Safety precautions would be those prescribed by the Occupational Safety and Health Administration for general construction and excavation as published in the Federal Register, Vol. 39, No. 132, Monday, June 24, 1974. No extraordinary precautions are required. Basically,

- Operators should visually inspect the dike twice a day for signs of stress or erosion.
- Operators should avoid inhalation of dust while mixing polymers.
- Effluent lines should be visually inspected for leaky fittings and corrosion.
- A chain link fence, a minimum of 3 m (10 ft) high, should be maintained on the edges of the lot to restrict public access. Such a barrier is already in place at the proposed site.

Sampling and Monitoring Requirements—

Background sampling and analyses are required to determine the presence of any contamination in ground water prior to construction of lagoon. This procedure should be conducted at two points: one beneath the proposed lagoon site and one downflow towards the shore of Lake Michigan.

Effluent discharges should be sampled and analyzed for suspended solids and PCB on a daily basis using composite sampling. Should high levels of PCB or solids be found (>10 ppm PCB), polymer dose should be adjusted or other additives applied. Similarly, more frequent visual inspections of effluent should be conducted to discover occasions of high solids carry-over. In the event of uncontrolled losses, dredging should be terminated and the spoils allowed to settle before operations are resumed.

After completion of dredging, pumps should be employed to remove standing supernatant. Sediments should then be left undisturbed until measurements reveal solids levels above 20% on a weight basis. At that point, out-loading for disposal can commence. Care must be taken to obtain a representative sample at depth below surface dried layers. Sampling wells should be monitored after completion of dewatering. Sampling and monitoring costs are estimated at \$5,000.

Time Needed for Completion—

Operation of the lagoon will coincide directly with dredging operations. An additional 2 weeks will be required to remove standing supernatant and allow settling. Time required for drying to 20% solids will depend on weather conditions.

Estimated Cost of Treatment—

Dredge Threshold - 100 mg/kd (ppm) PCB

Lagoon Construction 120 x 120 m - 5400 m ³ at \$6.7/m ³ (400 ft x 400 ft x 10 ft - 7040 yd ³ at \$5/yd ³)	- \$ 35,200
Lagoon Seal	- 85,200
Discharge Pipe 180 in at \$23/m (600 ft at \$7/ft)	- 4,200
Engineering (10% of cost)	- 12,400
Operating cost (12 hr-2 hr/day, 6 days at \$10/hr)	120
Cost of Polymer 27,000 m ³ at \$0.60/m ³ (35,000 yd ³ at \$0.45/yd ³)	- 1,610
	- \$ 138,730

Dredge Threshold - 10 mg/kg (ppm) PCB

Lagoon Construction 120 m x 150 m x 3 m - 9400 m ³ at \$6.7/m ³ (900 ft x 500 ft x 10 ft - 12,320 yd ³ at \$5/yd ³	- \$ 61,600
Lagoon Seal	- 237,000
Discharge Pipe 180 m at \$23/m (600 ft at \$7/ft)	- 4,200
Engineering Cost (10% of cost)	- 30,280
Operating Cost (32 hr - 2 hr/day, 16 days at \$10/hr	- 320
Cost of Polymer 78,000 m ³ at \$1.60/m ³ (102,000 yd ³ at \$0.45/yd ³ treated)	- 4,690
	<u>\$ 338,090</u>

Dredge Threshold - 1 mg/kg (ppm) PCB

Lagoon Construction 300 m x 240 m x 3m - 12,000 m ³ at \$6.7/m ³ (100 ft x 800 ft x 10 ft, 15,840 yd ³ at \$5/yd ³)	- \$ 79,200
Lagoon Seal	- 421,000
Discharge Pipe 180 m at \$23/m (600 ft at \$7/ft)	- 4,200
Engineering (10% of cost)	- 50,440
Operating Cost (54 hr - 2 hr/day, 27 days at \$10/hr)	- 540
Cost of Polymer 132,000 m ³ at \$0.60/m ³ (173,000 yd ³ at \$0.45/yd ³)	- 7,960
	<u>\$ 563,340</u>

Disposal

Equipment and Manpower Requirements—

The preferred option for disposal is burial at the Browning-Ferris landfill near Zion, Illinois. This commercial operation has already established the required procedures for transportation and burial of wastes. Manpower and equipment requirements other than those supplied by Browning-Ferris are limited to front loaders and operators to remove the dewatered spoils and load them into trucks for transport. It should also be noted that expeditious disposal will require removal in a 3 to 6 month period. Weight limitations will restrict trucks to 15 m³ (20 yd³)/load. Hence, 1750 to 8650 truckloads will be required depending upon the dredging threshold selected. This is equivalent to 13 to 66 truckloads/8 hr work day over a 6-month period. If a single truck averages 1 hr/round trip [19 km (12 mi)] one way, 2 to 8 trucks would have to operate continuously during the 6 months.

Safety and Environmental Precautions—

Safety and environmental precautions can be grouped into several general statements.

- Operations should be suspended on days of high wind velocity.
- Trucks should have tight sealing dump gates and be covered prior to departure from the lagoon.
- Shipments should be scheduled to avoid having trucks on the road during rush hours.
- Transport should be conducted in compliance with all hazardous waste and transportation regulations.
- All disposal operations must be conducted in compliance with the disposal permit.
- All trucks and loading equipment should be cleaned prior to use for subregional activities. Cleaning can best be accomplished by swabbing with oil soaked rags, which can be placed in the landfill for disposal.

Sampling and Monitoring Requirements--

Daily samples of dewatered sediment should be taken and analyzed to support records for the landfill. At the same time ground water and leachate monitoring should be continued at the landfill per standards imposed by the State and U.S. EPA. Cost for analysis of the sediment samples over a 6-month loading period will be included as a part of the disposal contract.

Time Needed for Completion--

Representatives from Browning-Ferris would prefer to complete disposal operations in a period of roughly 6 months. Hence, burial should be conducted at 210 to 990 m³ (270 to 1300 yd³)/working day depending on the amount dredged. This time schedule is also desirable in that it will allow completion prior to the onset of the winter season.

Estimated Cost of Disposal--

Dredge Threshold - 100 mg/kg (ppm) PCB

Cost of Loading 27,000 m ³ at \$1.3/m ³ (35,000 yd ³ at \$1/yd ³)	- \$ 35,000
Cost of Transportation 27,000 m ³ at \$6.7/m ³ (35,000 yd ³ at \$5/yd ³)	- 175,000
Cost of Disposal 27,000 m ³ at \$33/m ³ (35,000 yd ³ at \$25/yd ³)	- 875,000
	- <u>\$1,085,000</u>

Dredge Threshold 10 mg/kg (ppm) PCB

Cost of Loading 78,000 m ³ at \$1.3/m ³ (102,000 yd ³ at \$1/yd ³)	- \$ 102,000
Cost of Transportation 78,000 m ³ at \$6.7/m ³ (102,000 yd ³ at \$5/yd ³)	- 510,000
Cost of Disposal 78,000 m ³ at \$13/m ³ (102,000 yd ³ at \$25/yd ³)	- 2,550,000
	- <u>\$3,162,000</u>

Dredge Threshold 1 mg/kg (ppm) PCB

Cost of Loading 132,000 m ³ at \$1.3/m ³ (173,000 yd ³ at \$1/yd ³)	- \$ 173,000
Cost of Transportation 132,000 m ³ at \$6.7/m ³ (173,000 yd ³ at \$5/yd ³)	- 865,000
Cost of Disposal 132,000 m ³ at \$33/m ³ (173,000 yd ³ at \$25/yd ³)	- 4,325,000
	- <u>\$5,363,000</u>

THE NORTH DITCH

After detailed evaluation of feasible alternatives, it has been concluded that restoration is best accomplished by use of a Mud Cat dredge followed by dewatering of sediments, sedimentation treatment of supernatant, and disposal at the Browning-Ferris landfill. As in the case of Waukegan Harbor, in-place fixation was found to be the lowest cost alternative, but is not recommended because of significant reservations about its legal status and long-term viability. Should these issues be adequately resolved, fixation may be the preferred alternative.

Implementation

Details for implementation of the recommended alternative are presented below for the North Ditch. Little is known of the 90 m (300 ft) stretch of contaminated Ditch upstream of the road crossing within the confines of OMC plant property. Consequently, no recommendations can be made with respect to this segment. Since the water treatment and disposal aspects have already been covered extensively in the previous section, only those pertinent to the Mud Cat dredge are given in this section.

Equipment and Manpower Requirements--

One single Mud Cat MC-10 dredge having a 3 m (10 ft) digging depth would be required on the project. Additional equipment would entail the following listing:

AEP - 1C	Discharge pipe package, standard (200 m) 8 in. UHD polyethylene pipe with aluminum floats - 450 m (1,500 ft)
AEP - 2	Cable and related harness equipment
AEP - 3	Service boat and motors
AEP - 4	Handtool set
AEP - 6	Spare parts kit
1AC521	Carrier pipe, UHD polyethylene, 20 cm x 5.7 m (8 in. x 19 ft), male and female couplings, including gasket.

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Extra Discharge Pipe and Connector

1AC520 Carrier pipe, UHD polyethylene 2.4 x 6 m (8 x 20 ft) 20 cm (8 in.) 8-bolt flange fittings each end, including bolts, nuts and washers (8 pcs. each) with float bands and links.

Some difficulties can be anticipated with respect to discharge-pipe handling. This can be overcome by taking 60 to 90 cm (200- to 300-ft) cuts and utilizing flexible lines between the dredge and the metal, overland discharge pipeline. A crew of three men per shift would be needed for dredge operation and pipeline handling. In all a total of nine men would be required to gain a 24-hr day dredging operation.

Safety and Environmental Precautions Necessary--

The topography of the North Ditch develops operational, property damage and personal safety problems. One bank of the ditch is supported by a sheet pile bulkhead driven in the earth to a depth of 6 m (20 ft). No problems are evident on this side of the Ditch. The opposite bank parallels a roadway that provides access to OMC's parking lot. This roadway is heavily used at the start and termination of the plant's work periods. The bank is short and steep and would have to be supported during contaminated sediment removal by any medium; otherwise earth sloughing would occur and road cave-in is possible. Temporary shoring does not appear as a practical approach since the dredging operation would proceed too rapidly to permit continual replacement of the shoring. Such shoring would also be very costly. Additionally, the stringers used to brace the shoring would block progress through the trench. The Department of Labor and OSHA have been consulted on the problem and they contend that the regulations contained in their "Construction Safety and Health Regulations" Subpart P - Excavations, Trenching and Shorings 1926.650; 1926.651; 1926.652 and 1926.653 would be applicable to the proposed project. To meet these requirements, the bank must be allowed to slough to a 1:1 slope or less. This may endanger the roadway at several points. However, if traffic were rerouted or restricted to a single lane, this could be accomplished at a much lower cost than sheet piling. Subsequent backfill would be packed and paved to replace the road according to approved standards for road construction. Adequate backfill exists at the proposed lagoon site to meet all needs. This would require a transportation distance of only one-half mile. The interruption of current traffic patterns would not be likely to last more than 30 days.

Pipes and abutments are known to exist below the sediments of the North Ditch. A survey of past records and mapping of obstructions should be conducted prior to dredging. One pipeline between the water plant and the Sanitary District treatment plant is being placed beneath the Ditch at this time. Upon completion of work, additional clean sediments should be pumped through the dredge system to remove residual contamination in pipes.

Sampling and Monitoring Requirements--

Prior to dredging, ground-water samples should be taken and analyzed to determine the extent of PCB contamination. This should be followed by periodic sampling during the dredging and subsequent to it. Two sampling points will suffice; one near the mouth of the Ditch and one in the area of heaviest contamination. Weekly sampling should suffice.

Subsequent to dredging, sediment samples should be taken and analyzed at (150 m) (500 ft) intervals in the Ditch to determine the effectiveness of the removal effort. These samples should be comprised of three grab samples taken across a transect and composited for analysis. The total monitoring effort will cost an estimated \$7500.

Time Needed for Completion--

On the assumption that the Mud Cat dredge would pump at a low $30 \text{ m}^3/\text{hr}$ ($40 \text{ yd}^3/\text{hr}$) due to pipeline handling and mechanical downtime, the project could be completed in 5 to 12 days.

Estimated Cost of Eliminating Contaminated Sediments--

It is concluded that with the dredge ready at hand and in operational status, it would be most practical to remove all contaminated sediments, with little concern for PCB ppm levels at various depths within the sediments. If the project were conducted on this basis the following estimated cost figures would be applicable:

Mud Cat Dredge MC-10 3 m (10-ft digging depth)

2 months rental (minimum base period)	\$13,000
Freight (both ways)	5,000
Insurance premium (2 months)	500
Accessory package to suit	
Project (flexible hose and couplings, floats, discharge line, powered small craft, etc.)	10,600
Operating costs (fuel, 3-man work crew, repairs, etc.) 288 hr at \$45/hr	12,960
Booster pump system	4,400
Training operators	No Charge
Crane rental 1 day (2 half-days)	\$ 360
	<u>\$46,820</u>

The topography of the North Ditch is such that one bank is supported by a steel bulkhead, while the bank adjacent to the privately owned (OMC) roadway has a natural slope. The available space between the roadway and the freshly dredged Ditch would not develop a natural and stable slope once it is cut to a depth of about 3 m (10 ft) without erosion threatening the northern lane of the private OMC road. Therefore, traffic must be temporarily rerouted and the road must be backfilled and repaved after dredging. The cost of this activity is estimated at \$50,000 for backfill and \$10,000 for surfacing. The cofferdam would be an additional \$1,000. Hence, total costs are estimated at \$109,000.

Treatment

Pertinent points for treatment of supernatant are discussed in the previous section on Waukegan Harbor. Incremental costs are estimated to be \$0.006/m³ (\$0.000023/gal) water treated. This amounts to:

Dredge Threshold 100 mg/kg (ppm) PCB	
29,000 at \$0.096/m ³ (7,600,000 gal at \$0.000023/gal)	\$ 175
Dredge Threshold 10 mg/kg (ppm) PCB	
48,000 at \$0.006/m ³ (12,600,000 gal at \$0.000023/gal)	\$ 290
Dredge Threshold 1 mg/kg (ppm) PCB	
74,000 at \$0.006/m ³ (19,400,000 gal at \$0.000023/gal)	\$ 446

Disposal

Pertinent points for disposal of sediments are discussed in the previous section on Waukegan Harbor. Incremental costs are estimated to be:

Dredge Threshold 100 mg/kg (ppm) PCB

Loading Cost 2900 m ³ at \$1.3/m ³ (3800 yd ³ at \$1/yd ³)	\$ 3,800
Transportation Cost 2900 m ³ at \$6.7/m ³ (3800 yd ³ at \$5/yd ³)	19,000
Disposal Cost 2900 m ³ at \$33/m ³ (3800 yd ³ at \$25/yd ³)	95,000
	<u>\$118,000</u>

Dredge Threshold 10 mg/kg (ppm) PCB

Loading Cost 4800 m ³ at \$1.3/yd ³ (6300 yd ³ at \$1/yd ³)	\$ 6,300
Transportation Cost 4800 m ³ at \$6.7/m ³ (6300 yd ³ at \$5/yd ³)	31,500
Disposal Cost 4800 m ³ at \$33/m ³ (6300 yd ³ at \$25/yd ³)	158,000
	<u>\$196,000</u>

Dredge Threshold 1 mg/kg (ppm) PCB

Loading Cost 7400 m ³ at \$1.3/m ³ (9700 yd ³ at \$1/yd ³)	\$ 9,700
Transportation Cost 7400 m ³ at \$6.7/m ³ (9700 yd ³ at \$5/yd ³)	48,500
Disposal Cost 7400 m ³ at \$33/m ³ (9700 yd ³ at \$25/yd ³)	243,000
	<u>\$301,000</u>

INTERIM MEASURES

The high levels of the North Ditch will continue to supply PCB to Lake Michigan if restoration activity cannot be accomplished prior to the next period of spring runoff. In recognition of this, temporary measures should be considered for minimizing desorption or resuspension during periods of high flow. Two approaches have been selected for possible use. Final selection will depend upon the estimated time delay before full-scale restoration since one approach has higher operating costs and a lower capital requirement. The two are described below:

Gravity Flow

The first approach evaluated would rely on use of a gravity flow culvert running in the bed of the North Ditch. Flow would be collected behind an upstream cofferdam above the zone of heavy contamination. It would then proceed downstream in the culvert to Lake Michigan. A second cofferdam would be placed at the downstream boundary of heavy contamination (Figure 33) to isolate runoff from that zone and prevent its downstream movement. The culvert would pierce this cofferdam enroute to the lake. The culvert would be sized at 183 cm (72 in.) diameter in a half round configuration 93 cm (36 in.) depth to carry the maximum storm flow of 1.3 m³/sec (45 cfs) at the railroad crossing. If flow is taken from the crossing to the point where Lake Michigan water backs into the Ditch channel, 630 m (2100 ft) of culvert will be required. The two cofferdams would consist of 38 m³ (50 yd³) of packed fill each. Based on current prices, this yields a total cost of:

630 m (2100 ft) Culvert Pipe at \$53.70/m	(16.11/ft)	
3 m (10 ft) bolted lengths		
Stiffener angles and rods at \$18.17/m	(5.45/ft)	
Installation at \$16.66	(5.00/ft)	
Total at \$88.53/m	(26.56/ft)	= \$56,000
76 m ³ (100 yd ³) Cofferdams at		
6.58/m ³ (\$5/yd ³)		
		= 500
	TOTAL	\$57,000

Pumped Transfer

The second approach would utilize the same system of cofferdams to isolate the heavily contaminated zone, but would pump ponded water 90 m (300 ft) north to the North Shore Sanitary District Wastewater Treatment basins. To accomplish this, a series (4) of 23 m³/min (6000 gpm) impeller type lift pumps would be placed near the reservoir section feeding 30 cm (12 in.) PVC pipe. Capital costs are estimated at:

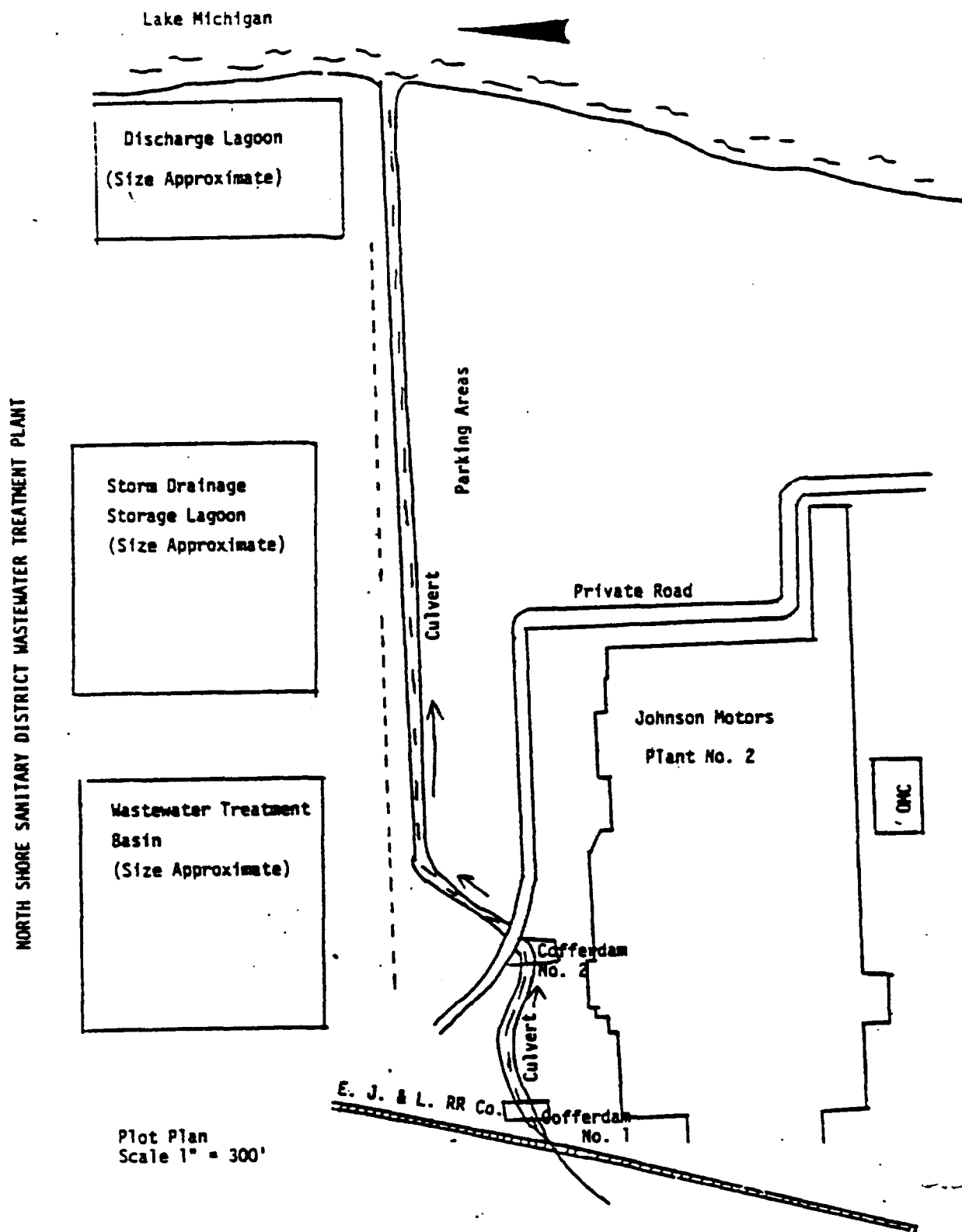


FIGURE 33. Placement of Interim Stormwater Rerouting Lines and Cofferdams

Pump unit	\$ 4,750
Pump setting assembly	748
Bushings, belts, etc.	200
Pump drive (50 h.p.)	670
90 in. (300 ft) 30 cm (12 in.)	
PVC at \$4.96/m (\$297/ft)	446
Float switch	127
	<u>\$ 4,947/unit</u>
	Total 4 units = \$19,760

Operational costs will depend upon the length of time pumping is required and the number of pumps required at any one time. Assume on the average that flow will require:

30 days with 4 pumps	= 120 pump days
30 days with 3 pumps	= 90 pump days
60 days with 2 pumps	= 120 pump days
245 days with 1 pump	= 245 pump days
	<u>575 pump days</u>

Each pump day demands 24 hr x 38 kW = 912 kW/hr
 912 kW/hr/day at \$0.02/kWh = \$18/day

Annual operation costs at 575 pump days x \$18/day = \$10,350

Labor and maintenance 3 hr/day at \$10/hr = \$10,950
 Total Annual Costs \$21,300

Hence, pumped transfer is the least costly of the two approaches if operation is to be less than a total period of 1.5 yr. Beyond that, the culvert option becomes less expensive. Use of the second approach would require approval by the North Shore Sanitary District.

SUMMARY COSTS

Based on current recommendations, it is estimated that total costs for restoration of Waukegan Harbor and the North Ditch will be \$1,660,000 to \$6,790,000 depending on the level of removal required. Details of these costs are provided in Table 36.

TABLE 36. Summary of Costs for Removing PCB Contaminated Sediments

Activity	Removal Threshold mg/kg (ppm) PCB		
	1	10	100
Waukegan Harbor:			
Dredging (hydraulic pipeline)	\$ 682,560	\$ 402,760	\$ 181,560
Dewatering-supernatant treatment	563,340	338,090	138,730
Disposal (Zion Landfill)	5,363,000	3,162,000	1,085,000
Sampling and monitoring	15,000	15,000	15,000
Subtotal (rounded)	\$6,620,000	\$3,920,000	\$1,420,000
North Ditch:			
Removal (Mud Cat dredge)	\$ 46,820	\$ 46,820	\$ 46,820
Backfill & road repair	61,000	61,000	61,000
Incremental supernatant treatment	446	290	175
Incremental disposal	301,000	196,000	118,000
Sampling and monitoring	7,500	7,500	7,500
Subtotal (rounded)	\$ 417,000	\$ 312,000	\$ 234,000
Total (rounded)	\$7,040,000	\$4,230,000	\$1,650,000

APPENDIX

TRIP REPORT CAPE FEAR RIVER DEMONSTRATION
PNEUMA DREDGE

J. L. Goodier

APPENDIX

TRIP REPORT CAPE FEAR RIVER DEMONSTRATION PNEUMA DREDGE

J. L. Goodier

The Pneuma dredge tests were conducted on the Cape Fear River under U.S. Army Corps of Engineers Headquarter's sponsorship. From what I understand the Pneuma S.p.A. of Tirenze, Italy, is no longer in existence. However, I could not actually confirm this at the test site. It appears that Richard Malablock; (a construction contractor) bought the present dredge, a model C unit, and, on the basis of operational malfunctions, has made numerous changes to the original Italian design.

The unit comprising the three cylinders, suction, and discharge pipes weighs 8 tons, exclusive of the weight of the compressed air supply and dredged material discharge hoses. These in themselves are of considerable weight. The equipment was raised and lowered by a whirly derrick on the deck of the Corps of Engineers' "snag boat," the SNELL. In overall dimensions the suction cylinders and component equipment are 18 ft from deck to the flexible suction hose connections, 9 ft from deck to the top of the cylinders and have a maximum breadth of 12 ft. Compressed air was provided from two Joy Manufacturing Company air compressors having a combined air supply of 2500 cfm. During the testing the compressors were operated at 800 cfm, each providing a total air supply of 1600 cfm at 75 psi. The compressed air was passed to the air "distributor" through a flexible hose line (4 in.). The distributor itself is a water jacket cooled, rotating cylinder that opens and closes air supply ports to each cylinder on a repetitive cycle. For some unexplained reason the cooling water discharge from the water jacket resulted in a heavy oil sheen appearing on the surface of the river. The only possible reason for this would be a crack or other defect in the wall of the water jacket permitting lubricating oil from the rotating piston valve to enter the water jacket. It should be noted that much of the compressed air supply was vented to the atmosphere through a vertical discharge pipe. This bleed off of air, although an obvious waste, maintained the air supply to the distributor and the submerged cylinders at a valve adjustable 20 psi. At deck level the noise of the air compressors was deafening (well in excess of OSHA's 90-decible, 8-hr exposure limit). All deck personnel within a 30 to 35 ft range of the compressors, of necessity, wore ear plugs or ear muffs. The bleed off of high pressure air through the atmosphere vent greatly contributed to the high noise level.

Once lowered into the water, at a depth of around 15 ft, the unit was primed with water before the air supply was directed into the pumping cylinders. At the bottom of each cylinder (3) there is an entrance pipe

through which the dredged material is drawn into the cylinder. At the top is a pipe for the introduction and release of compressed air, and a pipe used to raise the dredged material to the surface (this pipe extends almost to the bottom of the cylinder). In each cylinder there is a valve above the entrance pipe that automatically closes when air is pumped into the cylinder. This nonreturn valve (as are all parts of the system) is claimed by the designer/manufacturer not subject to wear and tear. During the tests I observed two of these valves lying at deck level with badly damaged rubber seals. The damage was obviously caused by rubber seal impact with the upper section of the intake pipe (see Sketches A, B, and C). Replacement of these valves is conducted through specially provided access openings.

When in operation the pump works in two phases.

- The dredge spoil flows into the cylinder, while the compressed air pumped into the cylinder escapes up the delivery line to the atmosphere (A) when the cylinder is filled, the nonreturn valve in the entrance pipe closes (B) - Compressed air is again pumped into the cylinder to expel the dredge spoil from the cylinder to the delivery pipe (C).

With the combination of three cylinders operating in different cyclic phases (as controlled by the distributor) there should be constant removal of the dredge spoil to the surface.

The main test of the Pneuma was commenced at 10:20 a.m. and a high velocity discharge of water was pumped into the Corps' hopper dredge, "CURRITUCK". This vessel was originally built as a self-propelled, split hull, dump barge in 1974. It was converted into a hopper dredge in 1976 by the installation of port and starboard suction drag heads and a pump system. The vessel fills her own hopper then proceeds to a preselected dump area, opens up her entire hull, and dumps the dredged material.

The basic characteristics of the vessel are provided since they later have bearing on our prognosis of the Pneuma tests.

STATISTICS

Length overall	150 ft
Width (over elbows)	31 ft 8 in.
Draft light	3 ft 8 in.
Draft loaded	7 ft 8 in.
Capacity (sand)	315 cubic yards

Propulsion	2 CAT D334-600 hp
Speed - light 11 mph	loaded 8 mph
Propulsion Drive	1-GM 12V71 Diesel-360 hp
Range Cruising	400 miles
Fuel capacity (diesel)	3,000 gallons
Crew complement	total 6
Normal operation	40 hr/week
Quarters and galley	-0-

The pumping continued for at least an hour with the dredge suspended from the crane cable. It was very obvious that only black colored water was being pumped, although a full bore discharge was maintained in the 10-in. diameter discharge pipe. The dredge operator (Tom Stafford of Pneuma North America) contended that the bottom of the river consisted of some 30 ft of silty material since the dredge eventually was registered to be at a depth of about 30 to 32 ft. At no time during the test was the crane cable slackened to place the dredge on the river bottom. Having operated a number of airlift dredging systems in similar type tests, I was not prepared to accept the dredger's concept of the geology of the river bottom. Based on the fact that the Cape Fear River is quite fast flowing and subject to strong scouring tidal action it would have been virtually impossible for the river bottom to be in such a silty condition. I concluded that the dredge had dug a hole in the seafloor and was dredging only the solids that sloughed into the dredged hole. I presented my opinion to the dredgers, the Army and EPA representatives. To substantiate my opinion I gained a water depth reading of 25 ft from the depth sounder on the "CURRITUCK". This was followed by my taking a lead line sounding in the immediate area of the Pneuma dredge - the solid river bottom was contacted at 15 ft. The Pneuma representative then lowered the dredge down onto the bottom and for the first time the dredge began to pump solids. For limited intervals the ratio of solids to water was obviously the greater, however, the dredge would pump solids, then choke down to a zero discharge. Pumping was never continuous; it came in bursts, then tapered down to a zero discharge as the content of each cylinder was emptied. A constant flow of solids was never maintained; the dredge did, however, prove to be a costly but effective water pump. The dump barge was finally filled at 1:20 p.m. after 3 hr of continuous dredging. The Captain of the "CURRITUCK" was convinced that he was in the range of 90% water to 10% solids. By contrast the "CURRITUCK" when operating as a dredge could fill her own hopper with some 315 yd³ of solids in a period of 18 to 20 min.

Prior to departure, action was underway to replace the straight suction horizontal digging shoes (3). The intent being to strap the Pneuma dredge to the side or stern of the "SNELL", then to dredge with the "SNELL" and the "CURRITUCK" moored alongside each other. The proposed action would take a

considerable amount of seamanship to secure the dredge to the vessel due to its configuration. The hydrodynamic forces that would be exerted onto the dredge, and the "hang up" of the suction shoes in the bottom sediments would create further problems. The support ship would of necessity need to proceed forward at a speed of at least 3 knots to maintain steerage. With the dredge on one side digging into the sediments, and the hopper barge on the other side, the support ship would tend to veer to the left, and the dredge, acting like a drag anchor, could possibly become a pivot. In any event, the fact that three digging shoes would be cutting trenches in the seafloor would raise solids into water suspension as would the propeller action of the support craft.

An alternative would be to mount the Pneuma dredge onto the ladder of a conventional hydraulic dredge to gain the wide swing action (easily up to 300 ft) associated with such dredges. This would, however, be of little avail, as the production of a hydraulic dredge, sans cutterhead, could readily exceed the Pneuma's production.

Since starting this report I have talked with Mr. David Frazier, President, Erickson Engineering Co., Inc., Tampa, Florida who confirmed the fact that the Pneuma organization in Italy has been phased out of business.

In Summation, the Pneuma Dredge system:

1. Lacks maneuverability;
2. Is exceptionally noisy at deck level when operation;
3. Has great difficulty pumping solid materials, and chokes when pumping solids at a higher ratio than water;
4. Presents difficulty from hose handling both at deck level and underwater (testing was greatly delayed when a chaffed hose line had to be replaced).
5. Presents no obvious advantages over a conventional hydraulic dredge and would not enhance same if mounted on a hydraulic dredge ladder for suction purposes.
6. The rubber seal or nonreturn valve on the suction inlet is obviously exposed to damage from forcible impact on the top of the inlet pipe and will warrant replacement in coincidence with the extent of dredge use.
7. When used in a towing mode, complete with cutting suction shoes, would greatly disturb the bottom sediments and place them in water suspension.
8. Required considerable deck space to house: two compressors (a noticeable decrease in the pumping action was evident when tests were conducted with air supply from only one compressor) air distributor unit, and the air supply and dredged material discharge lines.
9. Wastes considerable quantities of compressed air when excess air delivered to the air distributor unit is bled off to the atmosphere for pressure and air supply reduction.

The dredge owner realizes the difficulties of the dredge and is presently negotiating for design assessment and modification. On this basis the dredge as viewed would fall into a prototype or test unit. This report

will eventually be extended by the addition of monitored test data for turbidity, flow rates, and solid to water ratio readings. This information will eventually be provided by Corps engineers operating out of the Water Experimental Station, Vicksburg, Mississippi.

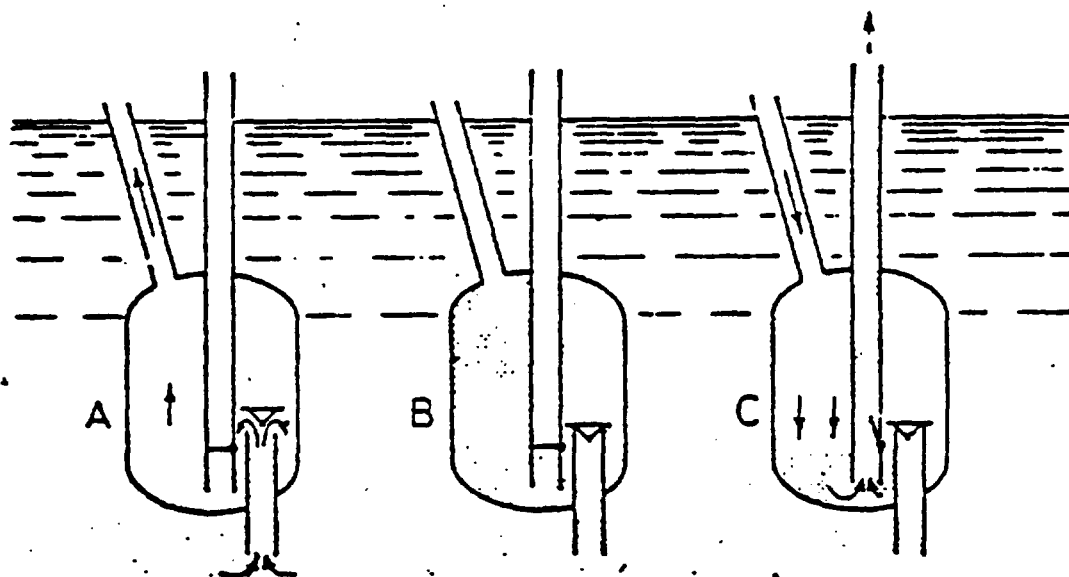


FIGURE A-1. Operating Cycles of Pneuma Dredge